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MFS-14552

GEORGE C. MARSHALL SPACE FLIGHT CENTER

AUTOMATED PATIENT MONITOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PQ2-5362U

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA 35812

IN REPLY REFER TO: MFS-14552

Dear Sir(s):

The attached reports describe the essential components and the basic design concepts of the automated patient care system devised by the Boeing Company under contract no. NAS8-20793. Specific circuit details are available but have not been included since the design is currently being reviewed and the packaging improved.

The system originated as a result of several requests from medical schools and researchers for a means of remotely monitoring several physiological parameters while still permitting the patients some freedom of movement. Two-way radio links eliminated the need for any 'hard wiring' to the patient, and FM and pulse-code-modulation techniques minimize the effects of outside electrical or radio interference. A common transmission frequency is used by all the patient monitoring units with complete control being exercised by the central control station. The patient monitoring units may be addressed in any order and at any time by the central station and do not transmit data unless specifically addressed, thus providing a truly random-addressable system. Each patient may be routinely monitored, or may be closely supervised, depending upon the instructions of the ward nurse, doctor, or computer diagnostic program.

The system is based to a great extent upon the concepts and circuitry now employed in the Saturn V launch vehicle telemetry system and has thus taken advantage of the latest developments in the field. The principle activity under the contract has been the necessary repackaging of the various circuitry to fit in the extremely small space within the patient 'wrist unit'. Use of LSI circuitry and microminiaturization should permit substantial reductions in size, if desired..(see B68-10065, Multichannel Implantable Telemetry System, Ames Research Center).

The complete system is currently undergoing test and evaluation at the MSFC Medical Center and it is hoped that the results of these tests will be available in the near future.

James W. Wiggins, Chief
Technology Utilization Office
Marshall Space Flight Center

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GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA 35812

The Technology Utilization Office was established by Congress and by the National Aeronautics and Space Administration specifically to identify and to communicate to industry those innovations, techniques, and concepts which have been developed by or for NASA and which have applications within the non-aerospace industries. Additional emphasis has recently been placed upon potential transfers to the medical and bio-engineering fields. Specifically, Biomedical Applications Teams have been formed to work with medical researchers in identifying problems and problem areas in medicine where there exist related NASA research programs which might provide partial or even complete solutions for these problems.

The device described in this publication is an excellent example of the type of transfer which we hope to see again and again as closer working relationships are established between medical researchers and their counterparts within NASA. You and your associates are invited to contact the Technology Utilization Office for assistance in identifying and obtaining such NASA derived technology as might benefit your research. Additional assistance is available through the Biomedical Applications Teams, administered by NASA Headquarters through Dr. Quentin Hartwig of the George Washington University, D.C.

J. Wiggins

James W. Wiggins, Chief
Technology Utilization Office
Marshall Space Flight Center

ABSTRACT

The Automated Patient Monitor is the direct application of telemetry system developed for and in support of the Saturn launch vehicle to a problem submitted by Dr. Ronald Lauer, pediatric cardiologist at the University of Kansas Medical Center (problem no. KU-4). Dr. Lauer requested multichannel, lightweight telemetering equipment which would free the patient for normal activity. Existing systems either required "hard wiring" the patient to the recording equipment, or were very limited in capabilities. Since the applications and requirements were very similar to existing systems within the launch vehicle telemetry system, it was relatively easy to devise a patient monitor which would satisfy Dr. Lauer's requirements and which had the advantage of circuitry which had been proved during actual launches. The Boeing Company, under contract to the Marshall Space Flight Center, miniaturized and repackaged the basic Saturn telemetry circuitry as shown in the attached contract Final Report. Since only a demonstration of the feasibility of such a system was required, no advantage was taken of the marked reductions in size and weight which can be achieved through modular and LSI techniques. The resulting system has performed well during demonstrations and is currently undergoing comparative tests at the MSFC Medical Center.

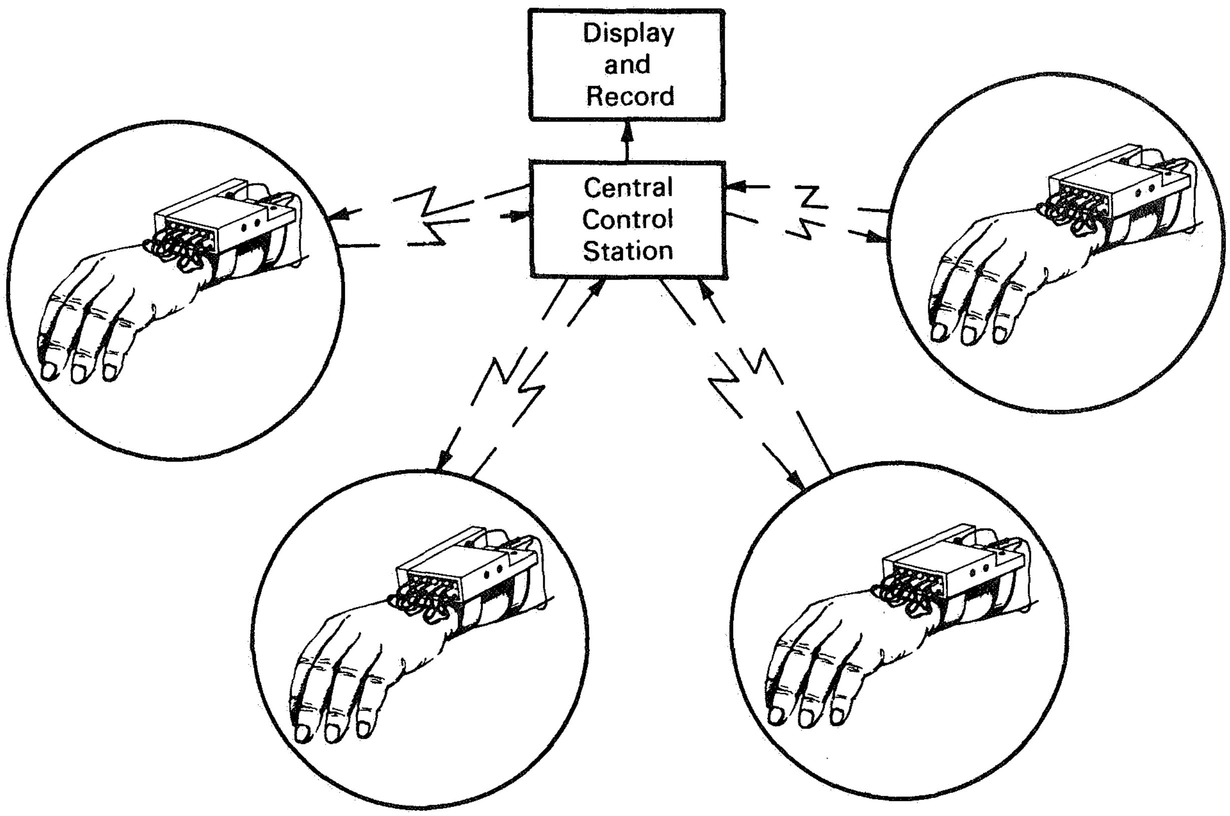
Brief abstracts are also given of certain related devices developed at the Ames Research Center in California; namely, a miniature implantable telemetry system designed for use with experimental animals, and an ultraminiature manometer-tipped cardiac catheter less than 1.5 mm in diameter which may be introduced into the vascular system by percutaneous techniques using standard 17 gauge thin wall needles such as are routinely used for venous or arterial punctures.

Finally, as an example of the wide range of ideas and concepts available to medical researchers, a brief mention is made of the preliminary investigations being undertaken into applications of various high-strength, high-purity carbons, graphites, and composites developed for aerospace applications but which appear to have wide potential as "replacement parts" for the human body. Early test results seem to indicate a high degree of bio-compatibility for several material formulations.

Further information on these or other NASA derived technology may be obtained from the Technology Utilization Office at the nearest NASA Center.

NASA TECH BRIEF

Automated Patient Monitoring System



A radio-linked patient monitoring system (designated "Automated Patient Care System"), which has been designed and placed into operation for feasibility testing, is capable of collecting several channels of physiological data from as many as 64 hospital patients and transmitting the data to a central control station. The information is transmitted in digital form which can be directly processed by a computer.

The system consists of a central control station and battery-operated patient units comprising small strap-on electronics packages designed to ensure minimum encumbrance and discomfort to the patients, who may be either ambulatory or bedridden. A complete patient unit including battery weighs less than one pound. Conventional biomedical sensors are associated with each patient unit. Typically, sensors include

(continued overleaf)

4 electrocardiogram electrodes, 2 thermistors for temperature measurement, and a strain gage consisting of a mercury-filled silicone rubber tube which is slipped over a big toe or a thumb to monitor blood pressure pulsations.

The central control station and patient units share a single broadcast frequency pair. A patient unit is not active until it is interrogated by the control station and signaled to transmit its data for central display and recording. During normal "all patients" operation, each of the patient units in the system is interrogated in turn for two seconds by a coded message from the central control station. In this period, the patient unit addressed transmits its data to the central station for display and/or recording. In the "single patient" mode of operation, any patient can be continuously monitored by setting a selector switch in the central station to the desired patient number.

Notes:

1. The feasibility of this system has been demonstrated in tests involving two patient units at distances of more than 125 feet from the central station. With further development, a system is envisioned which would enable several central stations to monitor the physiological condition of a large number of patients for routine detection and treatment of disease. Particularly advantageous application of this system would be in intensive-care wards.
2. With appropriate selection of transducers and signal conditioning circuitry, the system could be used to monitor a wide variety of industrial processes.
3. A related multichannel implantable telemetry system is described in Tech Brief B68-10065. Inquiries may also be directed to:

   Technology Utilization Officer
   Marshall Space Flight Center
   Huntsville, Alabama 35812
   Reference: B68-10131

Patent status:

Inquiries about obtaining rights for the commercial use of this invention may be made to NASA, Code GP, Washington, D.C. 20546.

Source: R. E. Bedard, W. S. Dawson, and R. L. Buxton of The Boeing Company under contract to Marshall Space Flight Center (MFS-14552)

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TITLE FINAL TECHNICAL REPORT - AUTOMATED PATIENT CARE SYSTEM

MODEL NO. CONTRACT NO. NAS8-20793

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JANUARY 2, 1968

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REV. SYM	DESCRIPTION	DATE	APPROVED
A	Added Appendix B Revised Pages iv, 2-1, 3-1, 5-11	7/24/68	R S Bedard

ABSTRACT

This document contains a description of the Automated Patient Care System designed and developed under NASA/MSFC Contract NAS8-20793. A sufficient number of schematics and photographs are included along with block diagrams to enable the reader to understand the system operation. Section 1.0 is an introduction and contains the statement of work. Section 2.0 is a block diagram description of the system written for the person interested in the system from a medical aspect. Section 3.0 has a summary of the results obtained from the prototype, and Section 4.0 lists several conclusions and recommendations. Section 5.0 is a technical description of the developed system. Appendix A contains photographs of the printed circuit cards, and the other sub-assemblies.

LIST OF KEY WORDS

Patient Monitoring System
Intensive Care System
Electrocardiography
Signal Conditioning
Data Processing
Circuit Miniaturization
Pulse Code Modulation/Frequency Modulation (PCM/FM)
Wireless Patient Monitoring
Metal-Oxide Semiconductors (MOS)
Large Scale Integrated (LSI) Circuits
Digital to Analog Conversion (D/A)
Biomedical Electronics
Patient Telemetry
Automated Patient Care
Analog to Digital Conversion (A/D)

CONTENTS

ILLUSTRATIONS

1.0 INTRODUCTION

The objective of contract NAS8-20793, "Design, Develop, Fabricate and Demonstrate an Automated Patient Care System" was to demonstrate the feasibility of acquiring physiological data from a human subject with a system that exhibited the three following important features:

a. The data acquisition equipment would be small enough to be attached to the subject with minimal encumbrance.

b. The data would be acquired over a wireless link.

c. The system would provide for simultaneous display of six channels of physiological data.

Such a system was developed and demonstrated to G. C. Marshall Space Flight Center. This system provided for acquisition, display and recording, from each of two subjects, of three channels of electrocardiographic data, two channels of temperature data taken from skin, oral or rectal sensors, and one channel of plethesmographic data obtained from a strain gage transducer attached to a toe or thumb. The system design has been based on sixty-four subjects, however, the feasibility was established by demonstrating with the two subjects.

2.0 SYSTEM DESCRIPTION

The Automated Patient Care System consists of a Central Control Station, shown in Figure 2-1 and up to sixty-four Patient Units, shown in Figure 2-2. The visual display and strip chart recorder used in the Central Station are commercial units that are used in patient monitoring systems wherein they are connected directly to the patient.

Referring to Figure 2-3, the general system operation consists of the operator, located at the Central Station, selecting the patient and data channel to be observed. No data is acquired from a patient without a request, or interrogation, from the Central Station. These requests, and the data from the patient, are processed for transmission over a radio frequency link.

The signals required to interrogate the patient units are generated, encoded and transmitted to the patients. During normal "ALL PATIENTS" operation, each of up to sixty-four patients is interrogated for two seconds by a coded message. During this two seconds, the patient addressed will deliver its data to the Central Station for display and/or recording. A continuous monitoring and recording capability can be initiated by switching the patient selector to "SINGLE PATIENT". In this mode of operation, any patient can be continuously addressed by setting the patient selector thumb-switch to the desired patient number.

Associated with each Patient Unit is an assortment of conventional medical sensors attached to the patient. These sensors include four electrocardiogram (EKG) electrodes, two temperature transducers which are encapsulated heat-sensitive thermistors, and one "toe" transducer which is a mercury-filled silastic tube slipped over the end of a big toe or thumb. This latter device is sensitive to blood pressure pulsations and is used to indicate pulse information. Provision is also made to monitor the critical patient unit power supply voltage.

The Patient Unit is battery operated, permitting complete freedom from wired connections to the patient.

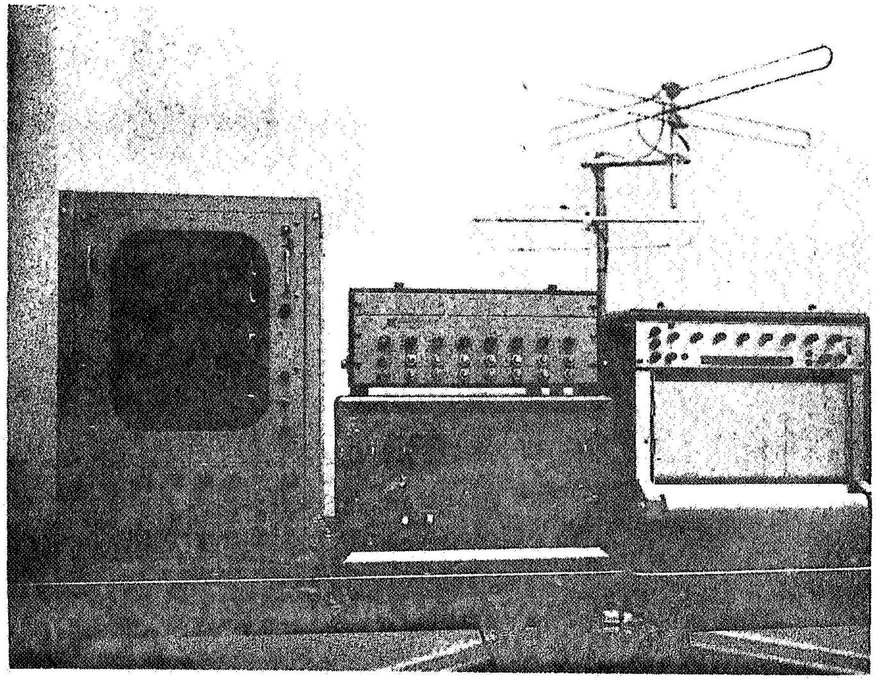


FIGURE 2-1: CENTRAL CONTROL STATION

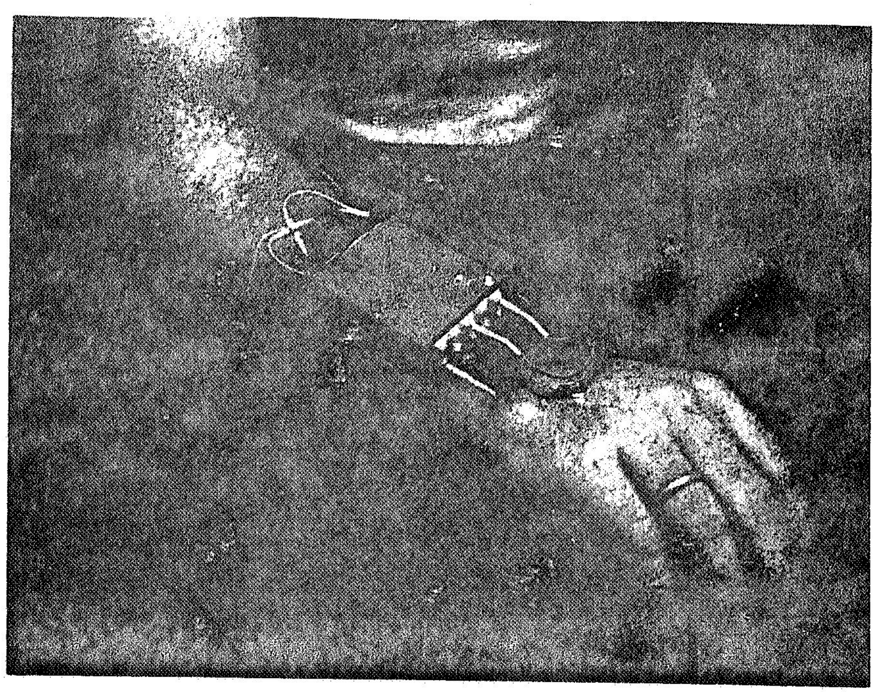


FIGURE 2-2: PATIENT UNIT

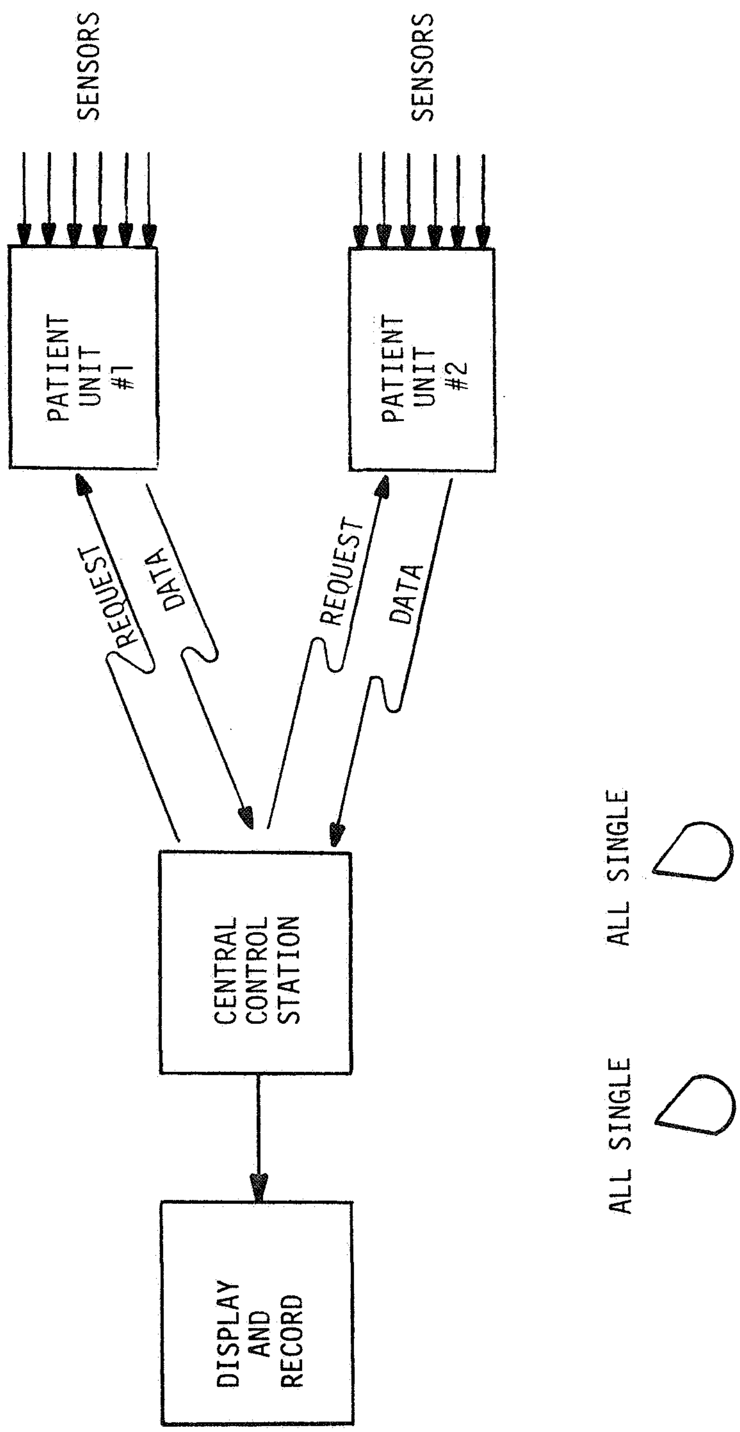


FIGURE 2-3: SYSTEM DESCRIPTION

3.0 RESULTS

In the limited time available for evaluation of the system it was determined that the approach was entirely feasible and the quality of the data was very good. Problems were experienced in the RF link due to outside interference and building structure effects.

Strip chart recordings taken with the system from a patient remotely located and mobile are shown in Figure 3-1. These waveforms were taken using chest electrodes placed at locations that minimize muscle movement artifacts. Patient temperature, both skin and oral, was obtained using calibrated voltmeters. This data was also obtained with the patient walking and performing running-in-place exercises. Equivalent results were obtained with the system compared to a commercial electrocardiogram machine (Hewlett Packard/Sanborn Viso-Cardiette) with the electrodes placed on the limb extremities.

Reasonable data was obtained from the "TOE" or plethesmograph sensor. However, this data had to be acquired while the patient was immobile (minimizing motion artifacts). The extremely high gain (15,000x) conditioning amplifier achieved adequate output levels for the very small changes in the sensor output caused by the patient's pulse.

The weight of the Patient Unit is approximately nine ounces and the patient battery pack slightly over six ounces, for a total weight emcumbrance to the patient of less than sixteen ounces. The corresponding volumes are nine cubic inches and six cubic inches for a total volume of fifteen cubic inches.

The patient battery pack life is calculated to be twenty-four hours at the normal scan rate of two seconds per patient every two minutes (2% duty factor). The life at 100% duty factor is on the order of twenty minutes.

Two frequency response values were obtained for the EKG and TOE channels: 200 cycles per second when all data channels are being observed, 340 cycles per second when only EKG and TOE are being observed. The accuracy of the signal conditioning averages 2% for all channels.

It was determined that a high level of RF interference caused occasional problems in transmission and reception resulting in loss of signal in some instances. Particularly troublesome in the Huntsville Industrial Center were those areas containing many electric office aids such as typewriters, adding machines and desk calculators. This interference caused occasional interruptions and erratic transmission and reception but did not cause erroneous data to be recorded. The accuracy of the information apparently was not affected by interference. Another source

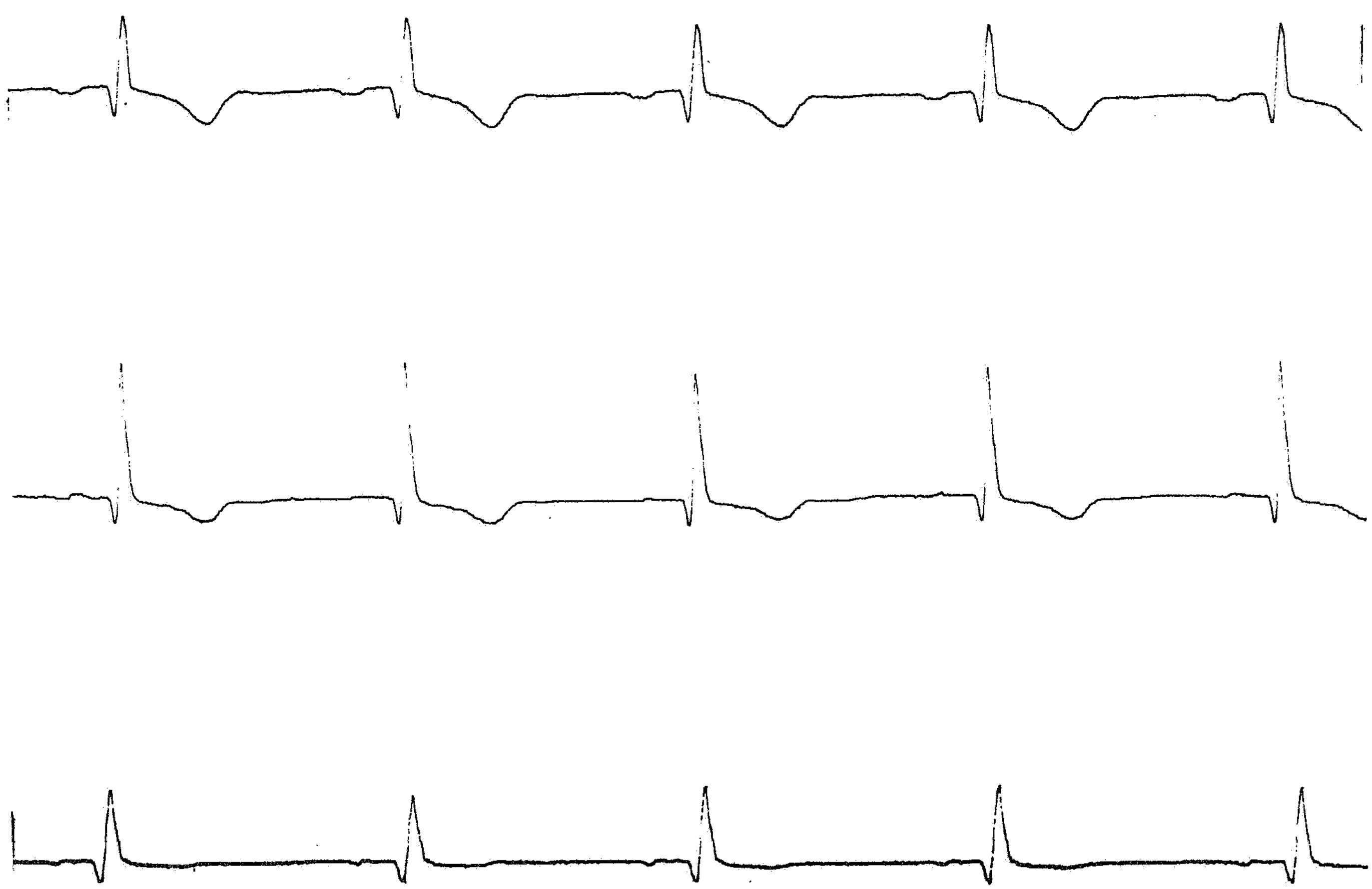


FIGURE 3-1: ACTUAL EKG WAVEFORMS (CHEST ELECTRODES - PAPER SPEED 50 MM/SEC)

3.0 (Continued)

of interference which caused occasional problems was determined to be from an electric arc welder located several floors below the area where testing was conducted. Here again, bursts of noise were observed, apparently when the arc was struck.

Serious consideration was given to what action could be taken to eliminate or minimize the effects of the interference discussed above. Methods for increasing the effective signal-to-noise ratio such as higher power levels from the transmitters, more sensitive and selective receivers, narrower bandwidths, different antenna configurations and signal polarizations, automatic gain control networks, and noise filters were considered. Also of interest was which RF link - to the patient, or from the patient - was being disturbed the greater. During tests conducted at a distance of fifty feet and through two or three plaster-board walls, indications were that the link from the patient to the central station was dropping out more often than the other, even though a bandpass filter was installed in the central station receiver line. It then began to appear that the simple and inexpensive central receiver was lacking in sufficient capture ratio and noise rejection capability in addition to having marginal sensitivity and quieting. Since it was not known exactly how severe an interference level was being experienced, a decision was made to install the equipment at G. C. Marshall Space Flight Center.

The testing at MSFC confirmed the suspicion that the down link was sensitive to interference in a high noise, low signal level environment such as is the case when the patient is at a considerable distance from the central station. A tunable VHF telemetry receiver was obtained and installed in the system. A noticeable improvement was observed in the number of signal "drop-outs" with this receiver. The central station transmitting antenna was also replaced with a vertically polarized dipole to further improve the operation.

The two patient units were used for additional tests and satisfactory operation was observed at distances of over 125 feet with two or three walls of unknown construction between the patient and the central station. Very few signal drop-outs were experienced except when the patients were in the furthest reaches of the area. Those losses of signal occurring within 100 feet of the central station were attributed to the effects of metal girders and structural members within the walls and ceiling of the area, and/or to extreme levels of interference from office equipment and operation of two elevators in close proximity to the test area. It is felt that an increase in central station transmitter power in conjunction with a more efficient antenna will eliminate these effects.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The objectives of the program as described in Section 1.0 have been met and the feasibility of a system such as described has been demonstrated.

During the development of the system, and its operation, areas requiring further study or development were identified and are described below;

a. The radio frequency characteristics of the typical hospital structure in which anticipated installations of the APC system might be made are not the same as those used and encountered in the development and demonstration of the currently existing system. Specific data link parameters were established in the feasibility program in order to minimize the equipment development and licensing problems for that system. The ultimate application of the system will require determination of the anticipated environment and development of the optimum data link.

b. In a typical application, the central station data would be operated upon for limit detection and alarm. Data storage and recall would also be made available for review of the patient's performance as an aid to diagnosis. The present system has been limited to conversion for display and recording only, which was adequate for feasibility determination. Techniques for limit detection should be determined and the interface with a digital computer for data storage and recall should be defined.

c. The current configuration of the patient battery pack has utilized readily available battery cells. Investigation should be conducted to reduce size and weight of these packs, with provision for recharging.

d. The present configuration of the APC system has utilized metal-oxide semiconductor (MOS) - large scale integration (LSI) circuits to the extent necessary for establishment of feasibility. Now that the digital design has been mechanized, it is desirable to have that configuration fabricated by a supplier in a total LSI configuration. The feasibility of LSI circuits for the data link equipment should also be established.

e. The current configuration of the system permits monitoring of three EKG channels, one "toe" channel and two temperature channels. The feasibility of processing other physiological parameters should be established.

5.0 TECHNICAL DESCRIPTION

The Automated Patient Care system consists of small, self-powered data acquisition equipment to be attached to the patient, and a central station capable of the command and control functions necessary to acquire, over a wireless RF link, seven channels of data from each of sixty-four patients and to subsequently display and/or record this data. The inherent requirements of the patient unit dictate that microminiaturization techniques be used exclusively in any final operating system. For this reason MOS circuitry was used in implementing the logic functions, since large scale integration techniques used in fabricating MOS logic are well established. The three shift registers and all of the A/D logic functions of the patient unit are themselves complex monolythic MOS devices. Of parallel importance to size is low power consumption in the patient unit. The approach used here was to first minimize the operating power and then to use power switching techniques so that significant amounts of power are consumed only during the time a patient is being interrogated.

Microminiaturization and low power techniques for the RF circuitry however, are somewhat more difficult. Consequently, it was necessary to simplify as much as practical the requirements and complexity of the RF link. For this reason a dual channel, binary coded FM data link was selected as showing the most promise in providing a secure, short range RF link.

5.1 DATA PROCESSING SUBSYSTEM

The data processing as considered herein consists of the circuitry directly associated with an operation on the data itself. This includes the collection, conditioning, multiplexing and analog to digital conversion processes of the patient unit, and the demultiplexing and reconversion functions of the central station equipment.

5.1.1 Patient Unit

The four main data processing functions of the patient unit are shown in the block diagram of Figure 5-1. The physiological data to be monitored is first collected by the appropriate instrumentation. This instrumentation consists of two basic types: electrodes attached to the patients skin, and used to sense the bioelectrical potentials generated by cardiac activity, and the second is the transducer. Falling in this latter category are the thermistors which are used to sense both internal and external temperature, and the mercury strain gage that is used as a volume transducer to provide an indirect blood pressure or pulse indication from one of the patient digits.

Due to the diverse types of instrumentation and the source impedance, signal levels, and frequency characteristics of the data to be monitored, a reasonably complex system of signal conditioning is necessary to prepare

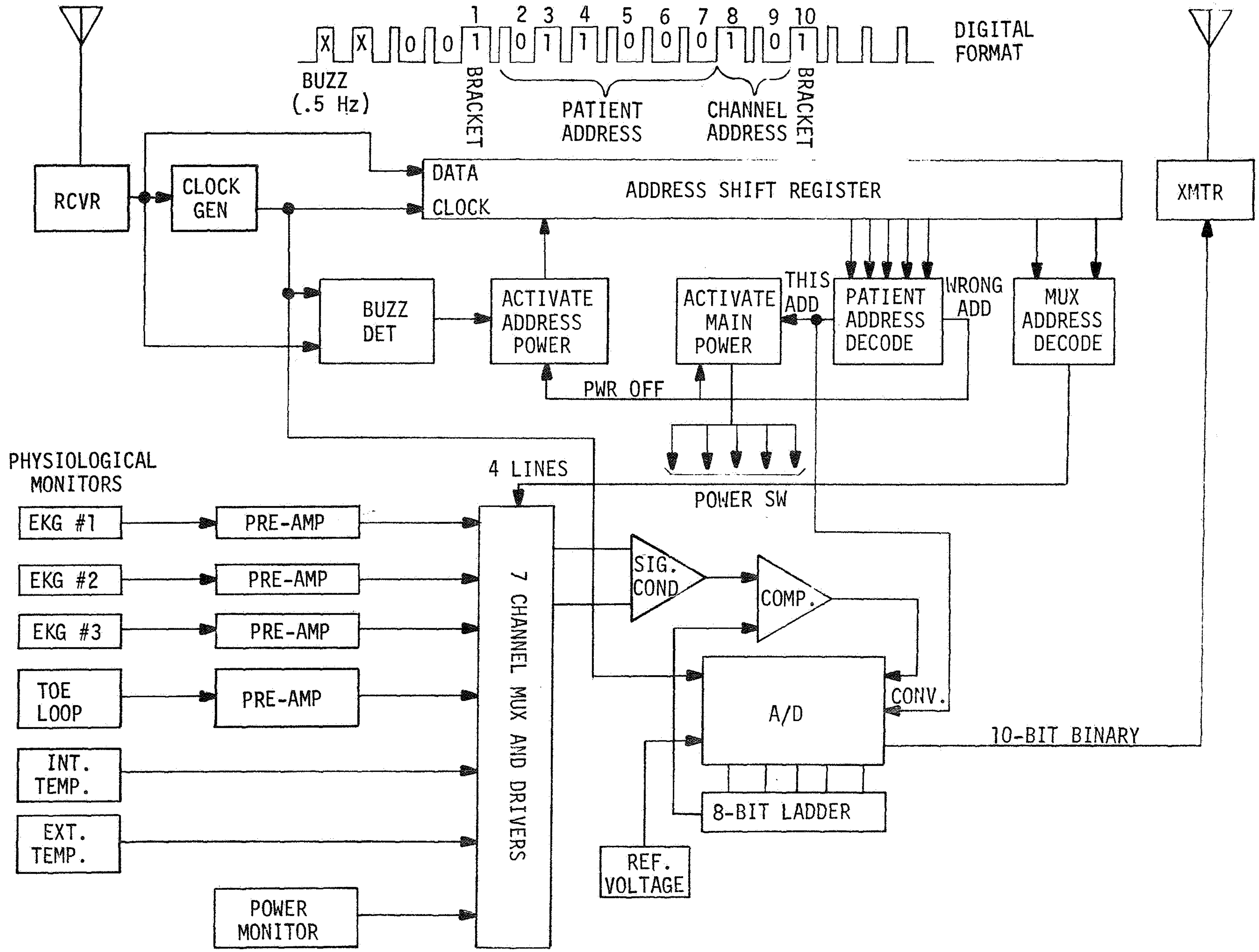


FIGURE 5-1: AUTOMATED PATIENT CARE BLOCK DIAGRAM, PATIENT UNIT

5.1.1 (Continued)

the data for multiplexing and ultimate conversion into binary form by the analog to digital converter. Signal conditioning is performed by impedance transformation and amplification of the low level signals such that a high level multiplexer may be used to sample the seven channels of data. The resulting pulse amplitude modulated (PAM) wave train is then fed into a single, programmable gain signal conditioner which establishes the quiescent levels and peak amplitude of the data which is required for interface compatibility with the 0 to 5V conversion capability of the analog to digital converter. The relative signal levels, frequency capability, and overall gain of the signal conditioning circuitry for the various channels are summarized as follows:

Channels	Signal Range	Overall Gain	Frequency
3 - EKG	0 - 10 mV	500	1 - 800 Hz
2 - Temperature	1 - 50 mV	100	DC - 800 Hz
1 - Pulse	0 - 30 μV	15,000	1 - 800 Hz

The multiplexing function that was mentioned previously is performed in dual, six-switch MOS devices which are programmed and activated by the appropriate logic circuitry. Since a high common mode rejection is necessary in the signal conditioning circuitry (to minimize artifacts and 60 cycle pickup) a two pole multiplexer switch is required to transfer the differential data lines. The common signal conditioner accepts the differential PAM signal from the multiplexer and converts it to a signle ended output which is then fed to the A/D converter.

The A/D converter is a successive approximation type operating at a 40 KHz clock rate and consists of single chip MOS logic circuitry, an 8-bit binary ladder network, a comparator, and a 5-volt reference source. The resulting 10-bit message contains eight bits of binary information and two time slots which are used to provide multiplexer switching and settling time. The binary data is then fed directly into the patient transmitter which establishes the RF link to the central station receiver.

5.1.2 Central Station

A block diagram illustrating the major functions of the central station equipment is shown in Figure 5-2. The data processing functions of this equipment are readily followed by starting at the receiver output and progressing to the right. The serial binary data is first "clocked" into a shift register whose parallel outputs are loaded into a binary weighted summing network where the conversion of the digital message back to an analog signal is accomplished. Since the data is being "clocked-in" continuously the output of the summing amplifier is a constantly changing analog signal but the data is valid only during the time the register is

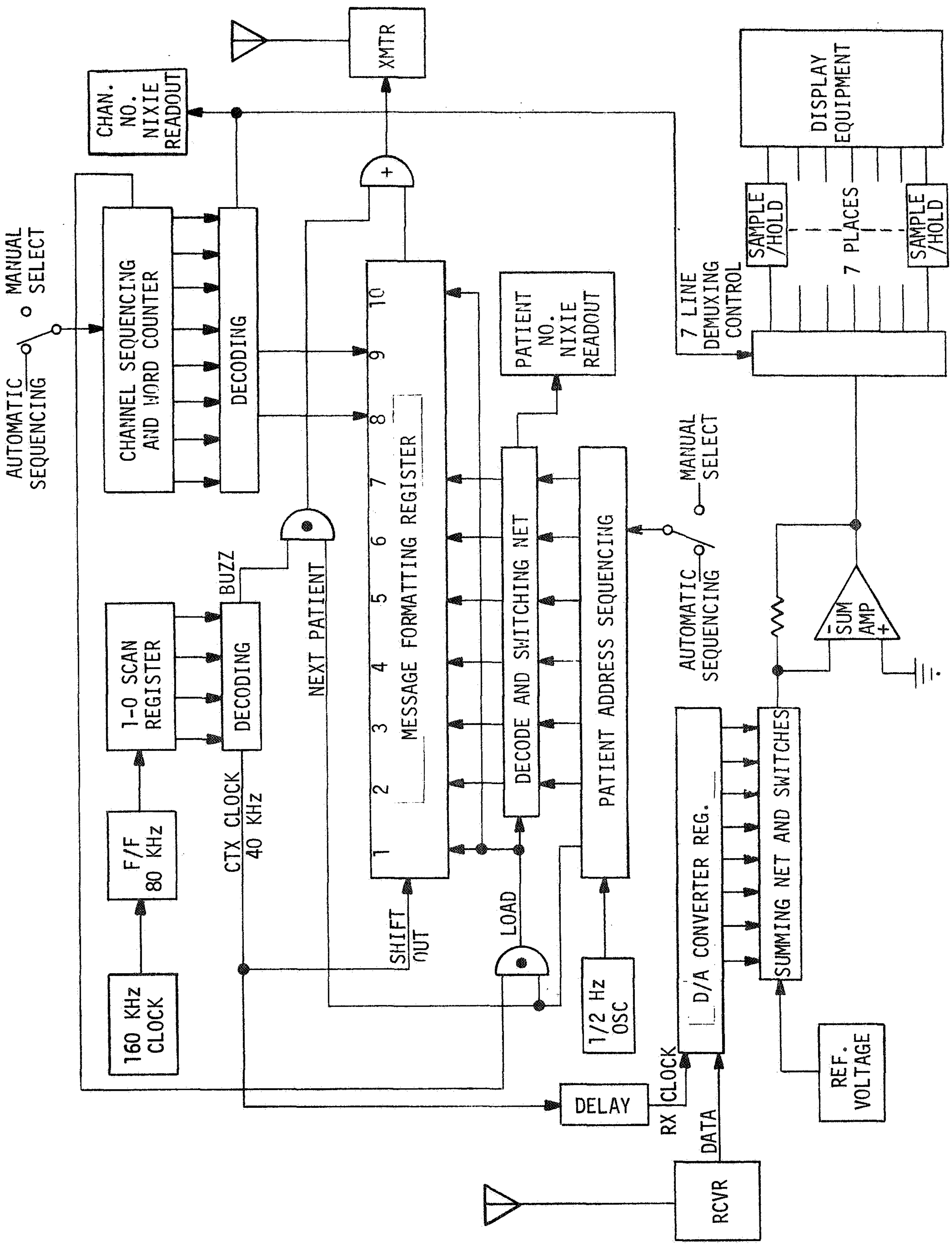


FIGURE 5-2: AUTOMATED PATIENT CARE BLOCK DIAGRAM, CENTRAL STATION

5.1.2 (Continued)

loaded with a single coherent word. For this reason the summing amplifier output must be correctly sampled before being demultiplexed into the seven original channels of data. Both of the above functions are performed in a seven-channel MOS switch network whose outputs are fed into sample and hold circuitry consisting of memory capacitors and junction field effect transistors driving operational amplifiers. The output impedance of these amplifiers is sufficiently low (less than 1 ohm at DC) to drive short transmission lines and the necessary display and recording equipment.

5.2 LOGIC SUBSYSTEM

The logic subsystem, as in the case of the data processing subsystem, has sub-functions which are located in both the central station equipment and the patient unit. The basic function of the logic subsystem is to supply all the command and control functions necessary in a randomly addressable data link.

5.2.1 Patient Unit

The primary logic functions performed in the patient unit include clock strip-out, and all of the command, decoding, and switching functions required such as address recognition (both patient and channel address), power switching, and start of conversion. Referring to the block diagram of Figure 5-1, the binary data from the receiver is fed into a clock generator where the clock timing information is stripped from the incoming signal and routed to the appropriate circuitry. Referring to the digital format illustrated in Figure 5-1, the BUZZ signal is followed two bit-periods later by the 10-bit binary coded signal which carries the patient address and the information channel address that is desired. In addition, a "bracket" pulse is always transmitted as pulse number one and ten, and is used to initiate address readout only when the address shift register is full, thus insuring a coherent word.

Following the BUZZ signal and resultant "address power activate" sequence, an address unique to only one of the possible sixty-four units is transmitted. All units which decode an incorrect address activate circuitry which automatically removes address power and returns the units to their inactive or quiescent state. In this way, the considerable power consumed in the address circuitry (168 mW) is reduced by a .013% duty cycle to an effective power consumption of only twenty-two microwatts. The standby power consumption of the logic circuitry which includes the clock generator, BUZZ detector, and power switching functions, amounts to 76 mW. When the address is decoded as a valid command by the addressed unit, the main power control circuitry is activated which switches on main power and thereby activates all the rest of the patient unit functions. Two of these functions are channel decoding, which activates the proper multiplexer channel, and the start conversion signal which initiates the analog to

5.2.1 (Continued)

digital conversion sequence. The 10-bit binary address is repeated for every 250 microsecond data sample which maintains positive synchronization and identity between central and patient units. Following activation, the patient unit will continue to respond to each correct address until an alternate patient address is decoded at which time internal logic functions operate to remove both address power and main power to return the unit to its former inactive state. In order for the unit to again respond to an address, a BUZZ signal (which is repeated at two second intervals) must precede a valid interrogation. During patient interrogation the total power consumed, (exclusive of receiver power) amounts to about 1400 mW; however, when interrogated for a two second period every one hundred and twenty-eight seconds, as is the case during normal operation, the approximately 1.6% duty cycle reduces the average power consumed to 22.6 mW.

5.2.2 Central Station

The central station logic circuitry has few constraints regarding power and size. Consequently, SCIC integrated circuit functions consisting of separate JK binary elements and DTL NAND/NOR gates are used to generate the various programming functions. Figure 5-2 depicts, in simplified block form, some of the more significant functions. The basic system operating frequency (40 KHz bit rate) is derived from a 160 KHz clock which is also used to develop the various pulse widths used in message encoding. The 0.5 Hz clock is used to drive the patient address sequencing counter and also to initiate the BUZZ insertion circuitry prior to each "next patient" command. An eight-stage counter is used to perform word counter operations and to generate the channel sequencing codes. The "five-bit" patient address code and the "two-bit" channel code are loaded through decoding networks into a 10-stage message formatting shift register where bracket control pulses are added in positions one and ten. The message is then serially shifted out and into the central station transmitter where the RF command link to the patient units is established. The automatic channel sequencing and address sequencing circuitry are both provided with manual override controls such that one patient and/or one channel may be called up for continuous monitor. The logic circuitry also provides the necessary binary codes to drive nixie readout tubes for visual indication of the patient and channel being interrogated. One other major function provided by the central station logic subsystem is the timing and demultiplexing signals required by the D/A and sample and hold circuitry for reconstituting the binary data from the patient units into visual displays.

5.3 RF SUBSYSTEM

The RF subsystem consists of a two-way wireless link operating in the VHF range at a minimum power level consistent with obtaining reliable two-way communication.

5.3.1 Central Station To Patient Link

The central station transmitter, shown in Figure 5-3, operates at 48 MHz at a power level of 100 mW measured into a 50 ohm load. Digital signals from the logic circuits modulate the transmitter to produce a PCM/FM output.

The oscillator is of a modified Colpitts type which uses a voltage sensitive capacitor (varactor) in the collector. The digital pulses are applied to the varactor causing an increase in frequency with an increase in voltage.

Following the oscillator is a buffer amplifier and two power amplifiers. The output of the transmitter is applied to the central station dipole antenna.

The patient receivers, shown in Figure 5-4, are fixed-tuned, RF amplifiers utilizing a slope-tuned detector as a frequency discriminator. No AGC or AFC capacility is incorporated and the sensitivity and noise figure are only sufficient to allow reception of proper signals from the central station. A bandpass filter is employed in the input as an aid in rejecting the signals from the patient transmitter. Prime consideration was given to keeping size, weight, and power consumption to a minimum.

The output of the patient receiver is an exact reproduction of the digital pulses applied to the modulation input of the central transmitter.

5.3.2 Patient To Central Station Link

The patient transmitter, Figure 5-5, operates at a frequency of 79 MHz with a power output of 50 mw into a 50 ohm load. Frequency modulation is accomplished by applying the digital pulses to the base of a Colpitts oscillator. The change in base current causes a change in base-emitter junction capacitance and provides a frequency change. The oscillator output is amplified by the buffer amplifier and applied to the patient antenna which is simply a thirty inch length of hookup wire coiled up and taped to the top of the 2" x 2 1/2" signal conditioning and logic module. Loading of the antenna is simplified by using a variable capacitor in the output of the amplifier.

The RF section of the central station receiver, Figure 5-6, is patterned after the patient receiver except for the addition of tuning capacitors and another stage of limiting. The discriminator output is increased by two stages of amplification, is inverted, and the output referenced to 3.3V to satisfy A/D requirements. As with the patient receiver, no AGC or AFC capability exists. Sensitivity of the central station is somewhat better than the patient receivers since the variable capacitors allow for finer tuning and selectivity. This greater sensitivity permits the use of a lower power patient transmitter. A bandpass filter is placed in series with the receiver input to reject the central station transmitter frequencies.

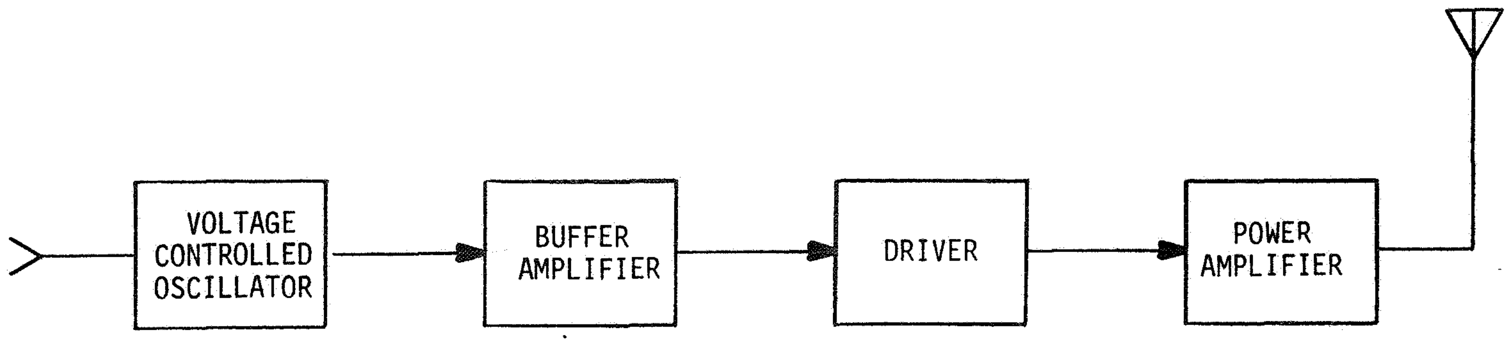


FIGURE 5-3: CENTRAL STATION TRANSMITTER BLOCK DIAGRAM

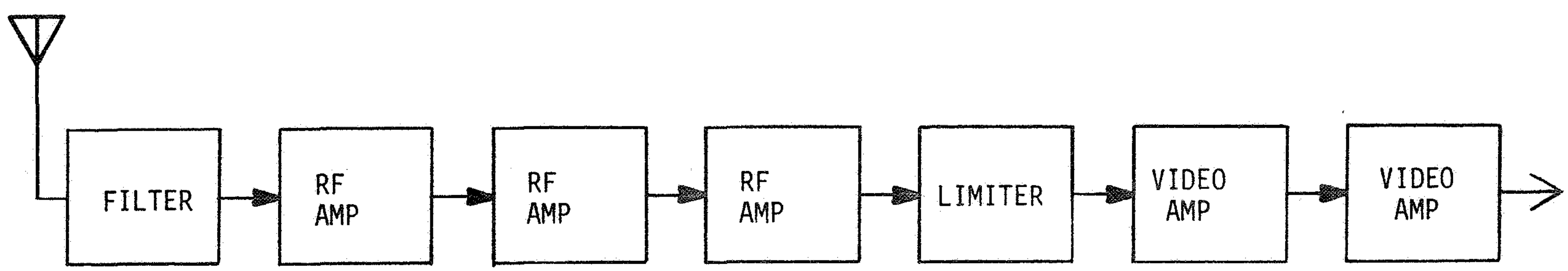


FIGURE 5-4: PATIENT RECEIVER BLOCK DIAGRAM

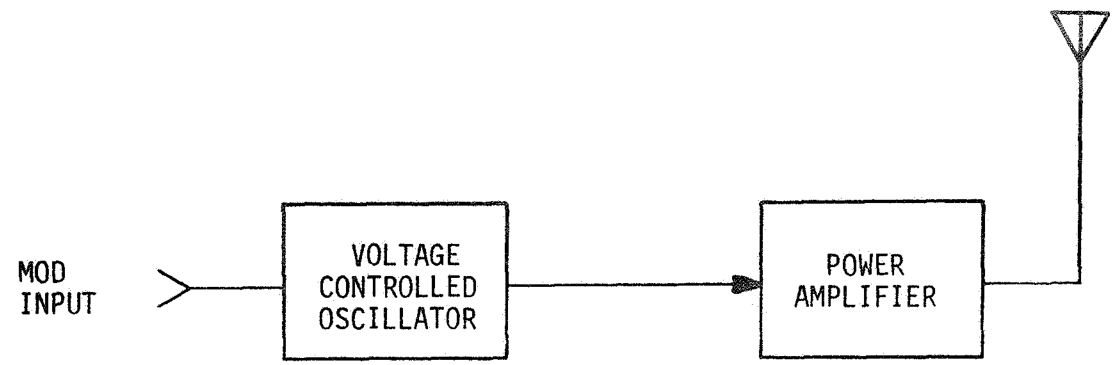


FIGURE 5-5: PATIENT TRANSMITTER BLOCK DIAGRAM

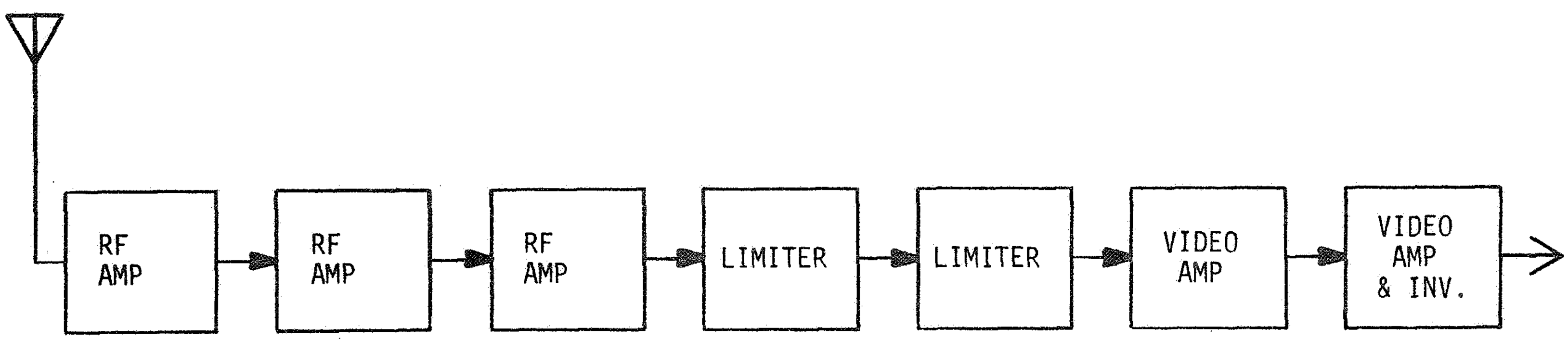


FIGURE 5-6: CENTRAL STATION RECEIVER BLOCK DIAGRAM

5.3.3 Frequency Selection

Several studies and trades were conducted to determine the best frequencies for use in the two way link. Of prime consideration was existing "traffic" in the area which would cause interference. Other important considerations included FCC regulations governing power levels and frequencies, and component size and availability.

The use of linear integrated circuits in the patient receiver was deemed desirable in order to keep size to a minimum. Inexpensive and readily available integrated circuits are designed for operation primarily below 100 MHz. Use of these devices at higher frequencies would have required more stages to compensate for lower gain per stage. Path losses and multipath effects also had to be considered at the higher frequencies.

Several frequency ranges were eliminated due to interference or as potential causes of interference. These ranges include the citizen's band, commercial FM band (88 - 108 MHz), amateur band (50 - 54 MHz) and several other bands used by local law enforcement, aircraft, etc. Two areas seemed particularly clear. The first was in the 40 - 50 MHz range and the second was in the 70 - 80 MHz range. The patient receiver was designed at the lower frequency to take advantage of the higher gain.

Two transmitters were designed for use in evaluating the chosen frequency ranges and comparisons were made with tests conducted using "walkie-talkie" transceivers at 27 MHz and 150 MHz. Results were favorable and hardware design centered on 79 MHz for the patient to central station link and 48 MHz for the central station to patient link.

5.4 POWER

The basic design goal used for the primary power source on the patient unit was that it be capable of operating for at least twelve hours at a five percent duty cycle and that its volume be no greater than six cubic inches. The demonstration unit displaces 5.85 cubic inches, weighs 190 gms, and supplies the required power for twenty-four hours in the normal scan mode of operation (i.e., 2% duty cycle). The basic building block for the battery pack is a 1.5 volt silver oxide cell rated at 160 mA hours of energy. Sixty-eight cells are combined in both series and parallel networks to supply the following energy and voltage levels.

$-13.3 \pm 1V$	505 mW @ 2% duty cycle plus 60 mw continuous
$+13.3 \pm 1V$	546 mw @ 2% duty cycle
$+1.25 \pm .25V$	115 mw @ 2% duty cycle

$-27.3 \pm 1V$ @ 248 mw @ 2% duty cycle plus 16 mw continuous

$+7 \pm 1V$ @ 102 mw continuous

5.4 (Continued)

Considering duty cycle and a twenty-four hour period, approximately 5000 mw-hours is required of the battery pack. In actual fact there is a specified 16,000 mw-hours of stored energy in the battery package; however, the accuracy of the data is degraded due to the change in voltage levels, beyond about 5000 mw-hours. The power switching circuitry consists of six series transistors configured for the most part to be driven directly by the MOS logic circuitry and to consume a minimum of power in the stand-by state.

5.5 PACKAGING

The requirements for a small, light weight package to be strapped to the arm of a patient dictate that considerable effort be expended on the micro-miniaturization and packaging of the Patient Unit. The approach uses small modular boxes fabricated from thin brass sheet metal. Seams and covers are made by soldering.

The Patient Unit consists of four major components: logic and data processing unit, receiver, transmitter, and battery pack. Organization and layout of components on the printed circuit cards used in the logic and data processing modules can be seen in Figures A-3, A-4 and A-5 of Appendix A. The complete patient strap-on unit is shown in Figure A-8.

The design goal for package size was thirteen cubic inches including power supply. The actual volume is fifteen cubic inches, nearly one third of which is battery pack. Subminiature, high energy batteries suitable for this application were unavailable and the final design utilized standard silver oxide hearing aid batteries.

No specific design goal was set for the weight of the patient unit but it was estimated that a strap-on device having a weight of over two pounds would be uncomfortable. The present unit weight is 15 3/4 ounces including the battery pack which weighs 6.6 ounces.

5.5.1 Logic and Data Processing Module

The logic, signal conditioning, and power switching circuitry of the patient unit are constructed on three 2" x 2" double-sided printed circuit cards which are hard wired together and packaged in a 2" x 2 1/2" x 1" brass case with feed through capacitors on all leads brought out of the enclosure. A photograph of a patient unit showing its "book-like" construction is shown in Figure A-6. This technique allows access to both sides of each card subsequent to final hard wiring to facilitate maintenance and checkout procedures. Figure A-7 shows the module out of its enclosure. In a practical system, some form of potting or conformal coating would also be used on each printed circuit card which would allow

5.5.1 (Continued)

for considerable physical abuse such as shock and accidental wetting. Power between patient electronics and the battery pack is supplied through a cable and a miniature 25-pin Winchester connector, while the input and output instrumentation and signal lead connections are made through individual miniature pins and pin jacks.

5.5.2 Patient Receiver And Transmitter

As in the case of the logic modules the receiver and transmitter are contained in small sheet metal modules fabricated such that the circuitry is easily accessible in a compact and light weight package. The majority of the space in the receiver is taken up by ferrite core inductors and integrated circuit amplifiers packaged in TO-5 cans. All components are mounted on printed cards in both the transmitter and receiver. Overall dimensions of the receivers are 3.8 x 1.0 x 0.54 inches. The dimensions of the transmitters are 1.82 x 1.0 x 0.57 inches. The receiver weight is less than 2.5 ounces and the transmitter weight is 1.6 ounces.

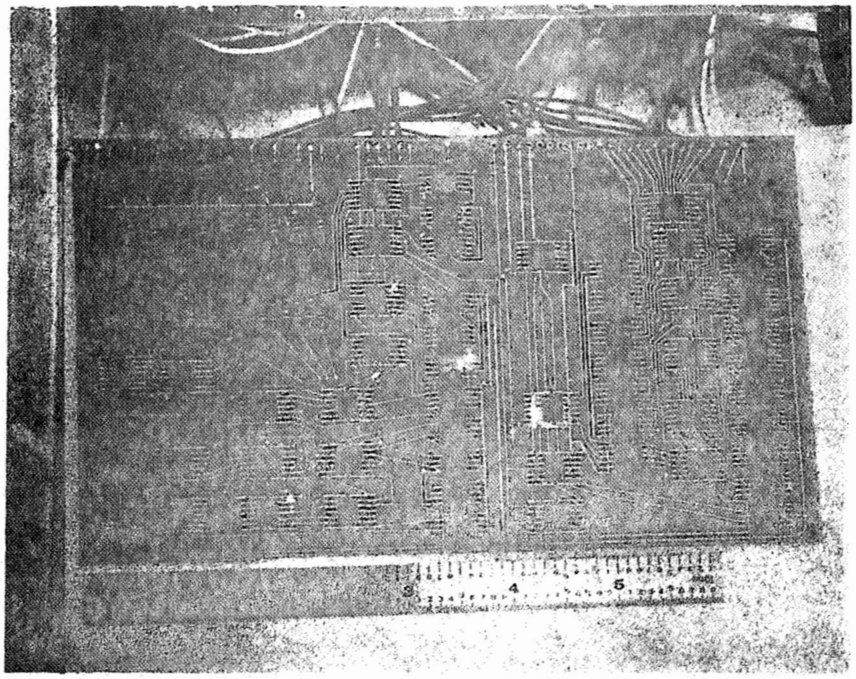
5.5.3 Battery Pack

The battery pack is fabricated using the Eveready S76E silver oxide cell as the basic element. These cells are 0.455 inches in diameter and 0.2 inches in height. Since both series and parallel combinations of the basic elements were necessary, the packaging approach used for the demonstration units consisted of stacks of cells under spring tension with ribbon leads welded to the end elements for the electrical connections. Sixty-eight cells are thus packaged in a 2.5" x 3.6" x .65" plastic case to produce the five voltages and 5000-mw hours of energy required. Total weight of the pack is 6.6 ounces.

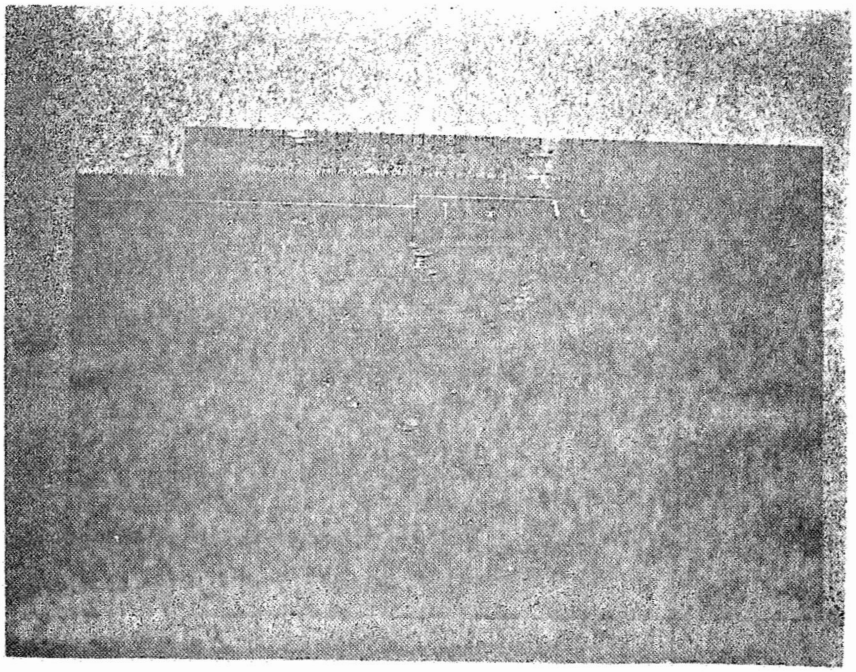
APPENDIX A

This section contains photographs of the various units used in the Automated Patient Care System.

Figures A-1 and A-2 show the large printed circuit cards used in the central station for programming, D/A conversion and sample and hold circuits. Figures A-3, A-4, and A-5 show patient logic and signal conditioning cards. Figures A-6, A-7, and A-8 show the patient logic and data processing unit in several stages of assembly. Finally, Figure A-9 is a photograph of the Patient Unit strapped on the wrist, and Figure A-10 shows the complete Central Control Station.

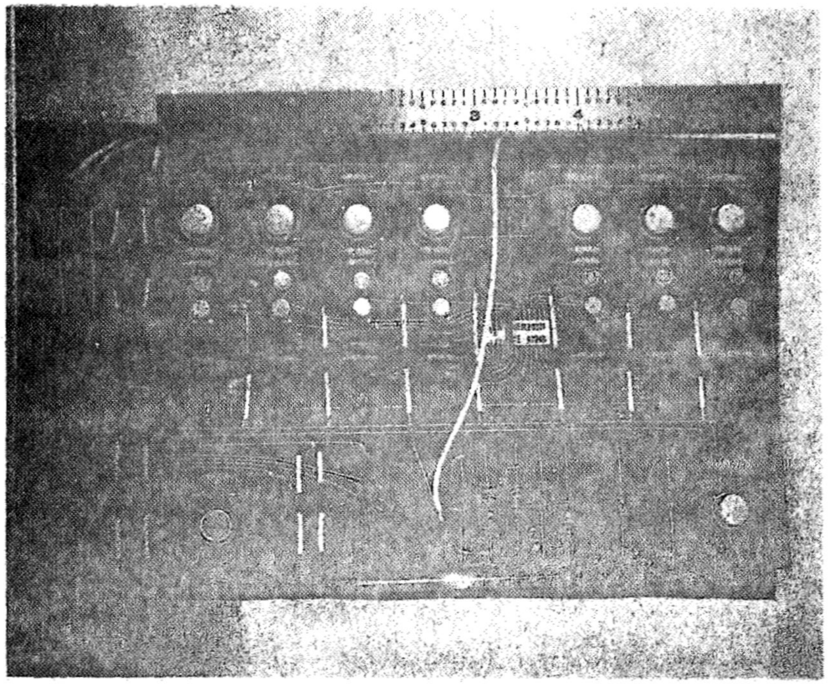


COMPONENT SIDE

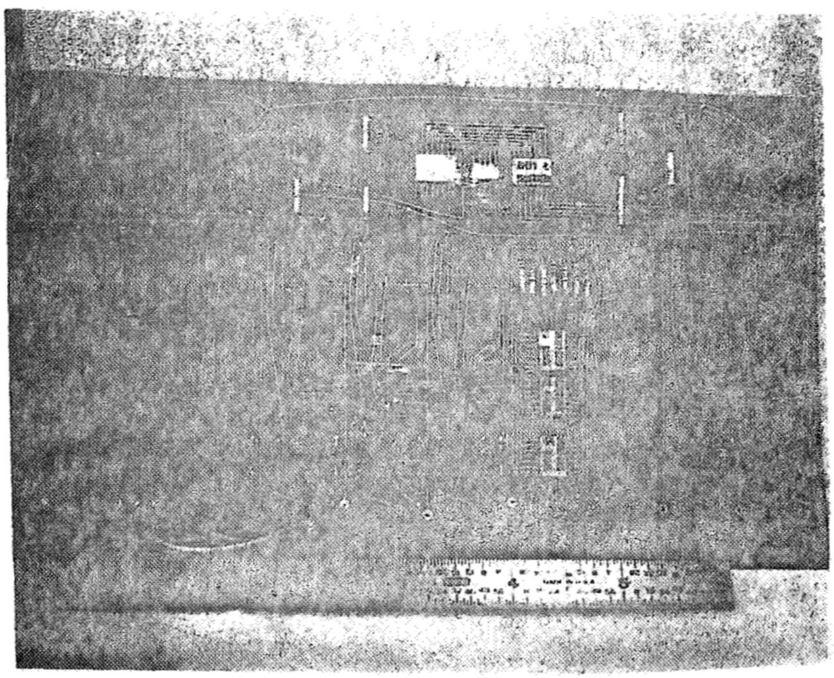


REVERSE SIDE

FIGURE A-1: CENTRAL STATION PROGRAMMER - PRINTED CIRCUIT CARD A2

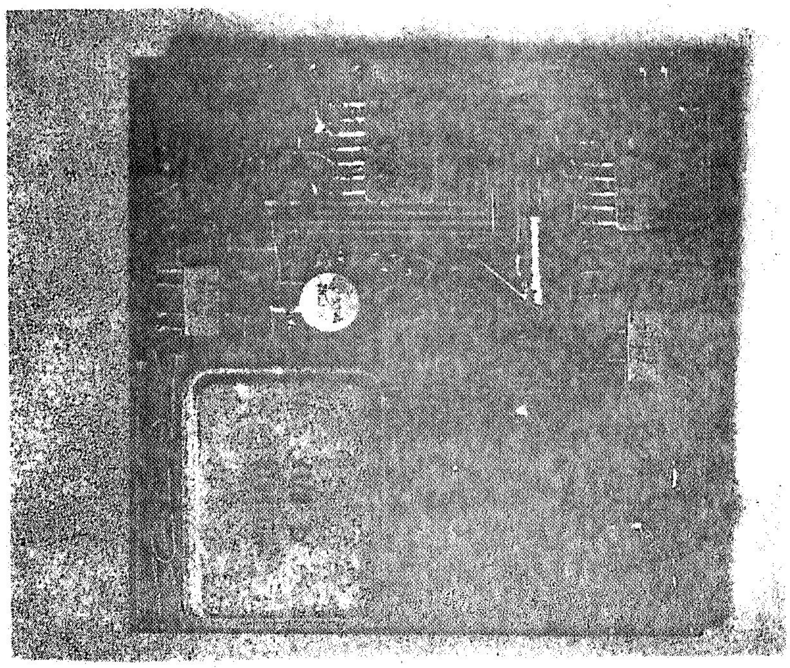


FRONT SIDE

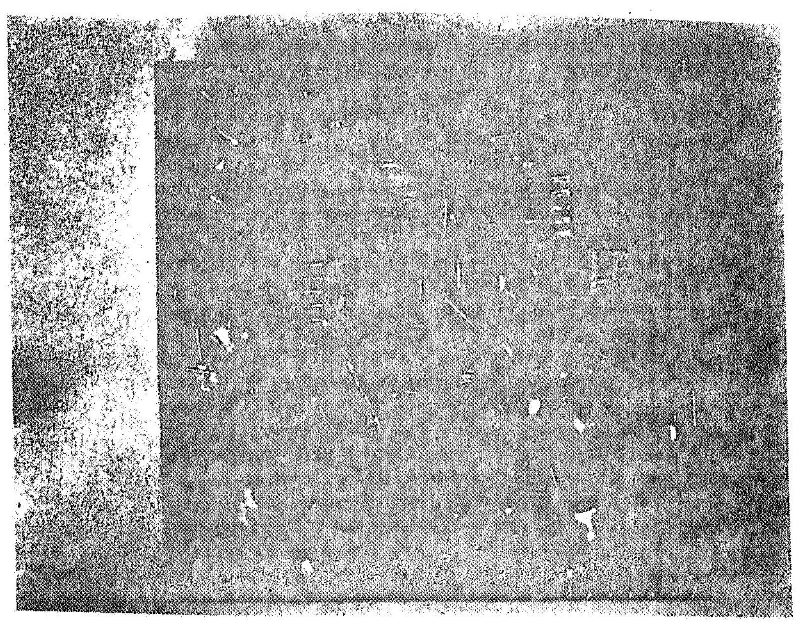


REVERSE SIDE

FIGURE A-2: D/A CONVERTER AND SAMPLE AND HOLD CIRCUIT - PRINTED CIRCUIT CARD A1

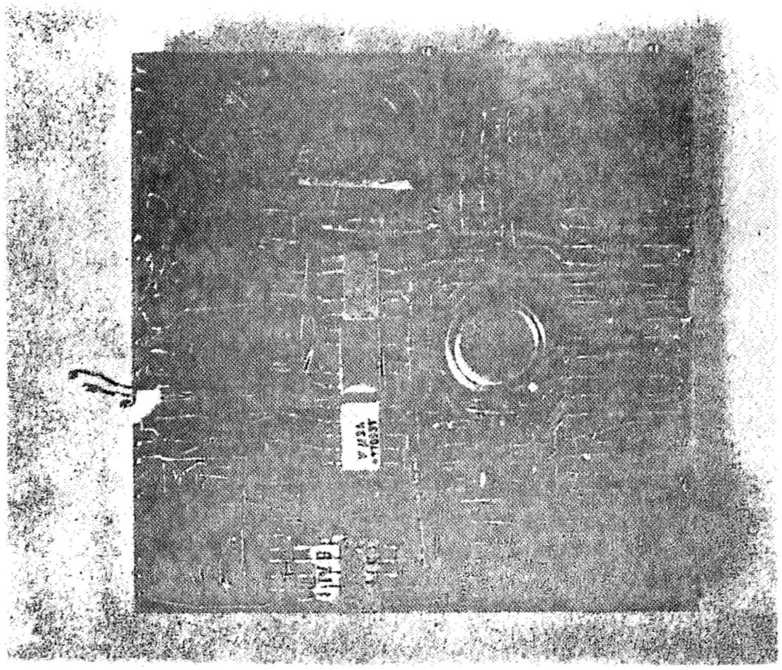


FRONT SIDE

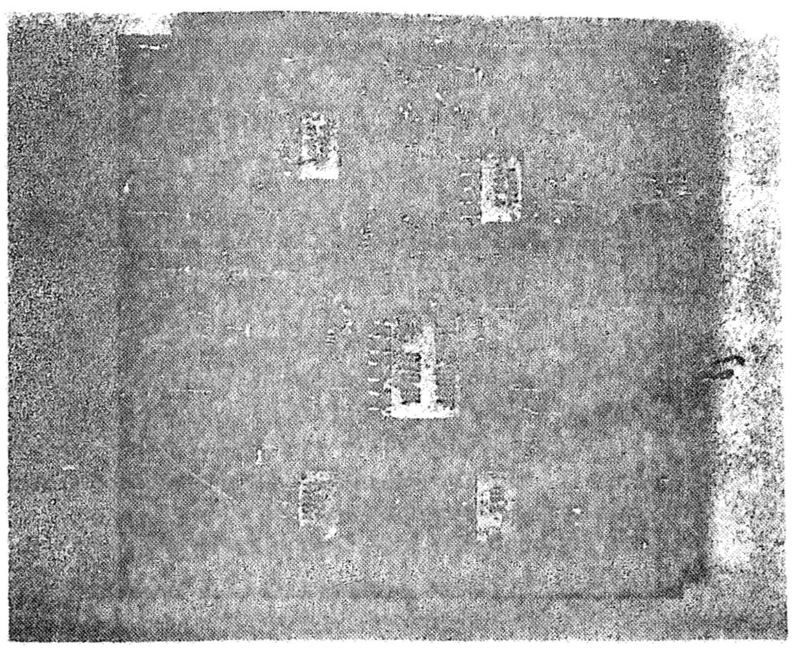


REVERSE SIDE

FIGURE A-3: PATIENT A/D CONVERTER AND POWER SWITCHING CARD

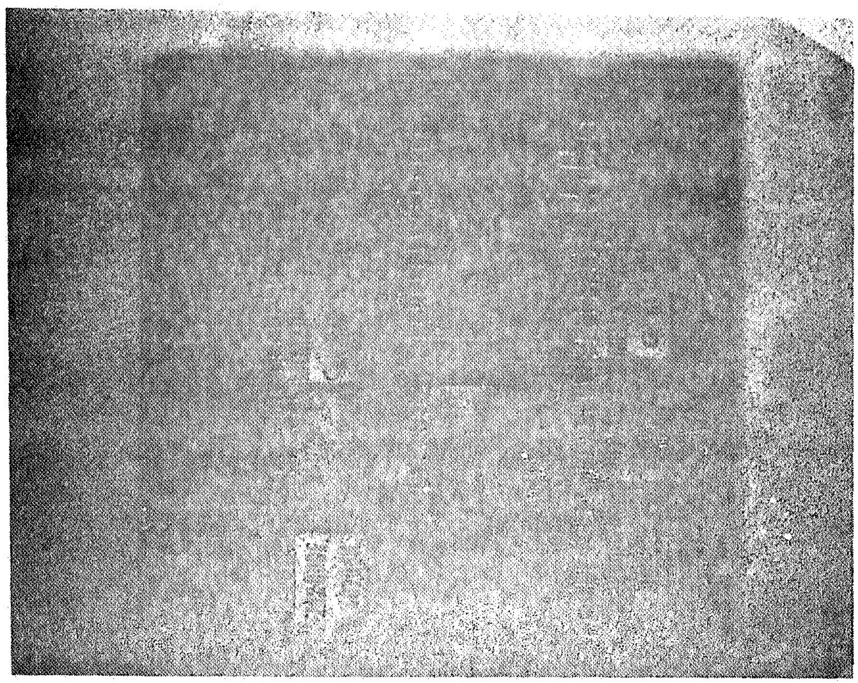


FRONT SIDE

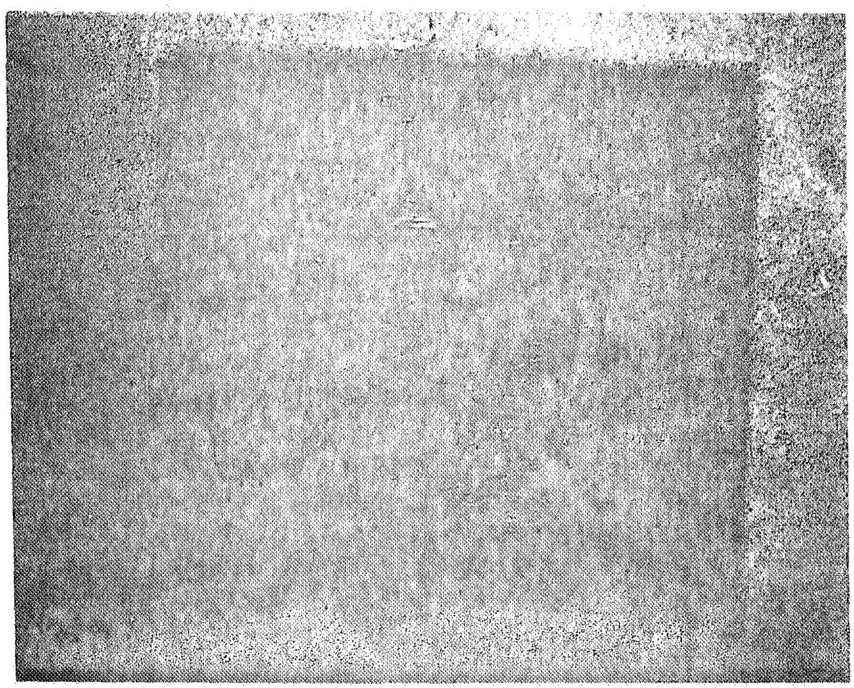


REVERSE SIDE

FIGURE A-4: PATIENT SIGNAL CONDITIONING CARD

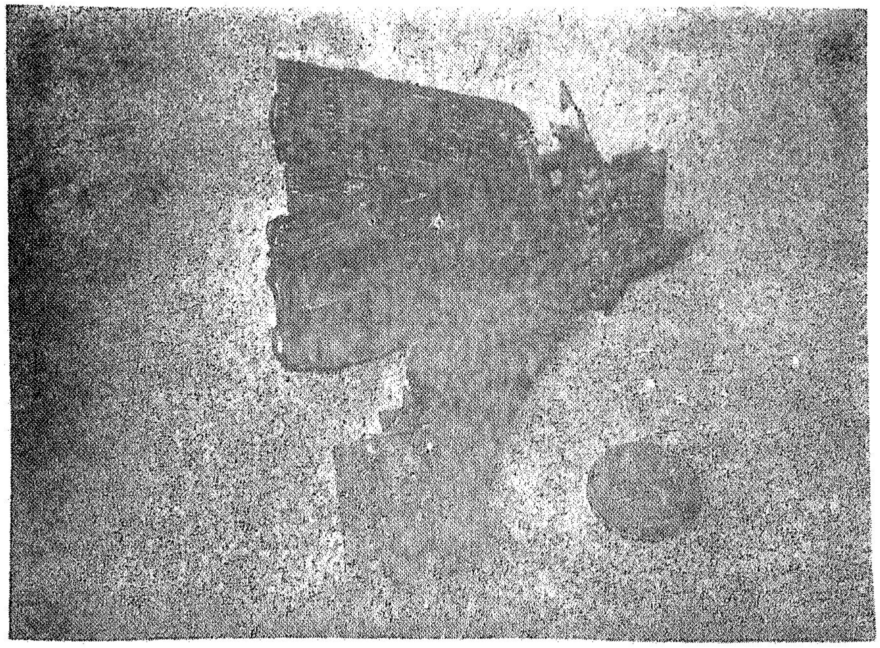


FRONT SIDE

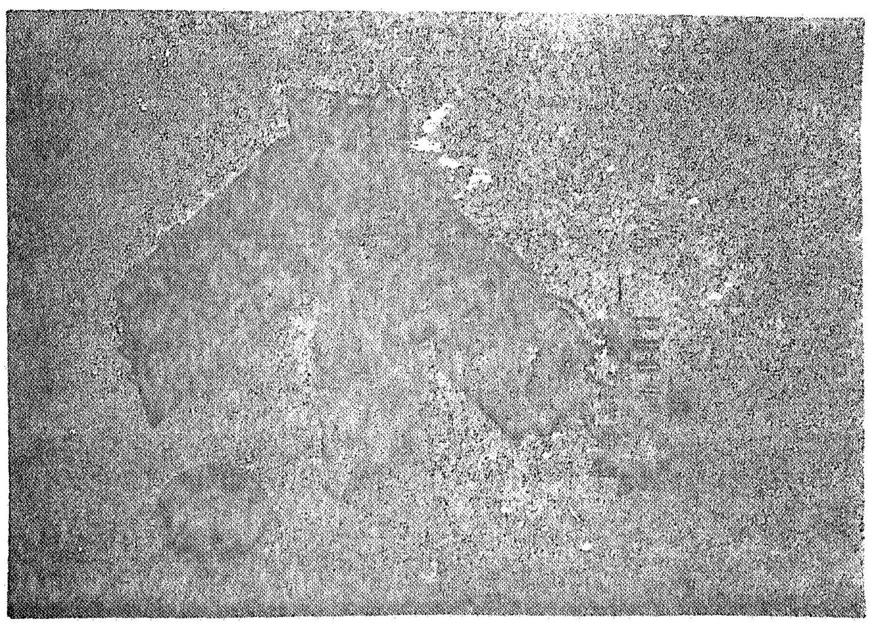


REVERSE SIDE

FIGURE A-5: PATIENT LOGIC CARD



VIEW A



VIEW B

FIGURE A-6: PATIENT LOGIC AND DATA PROCESSING UNIT

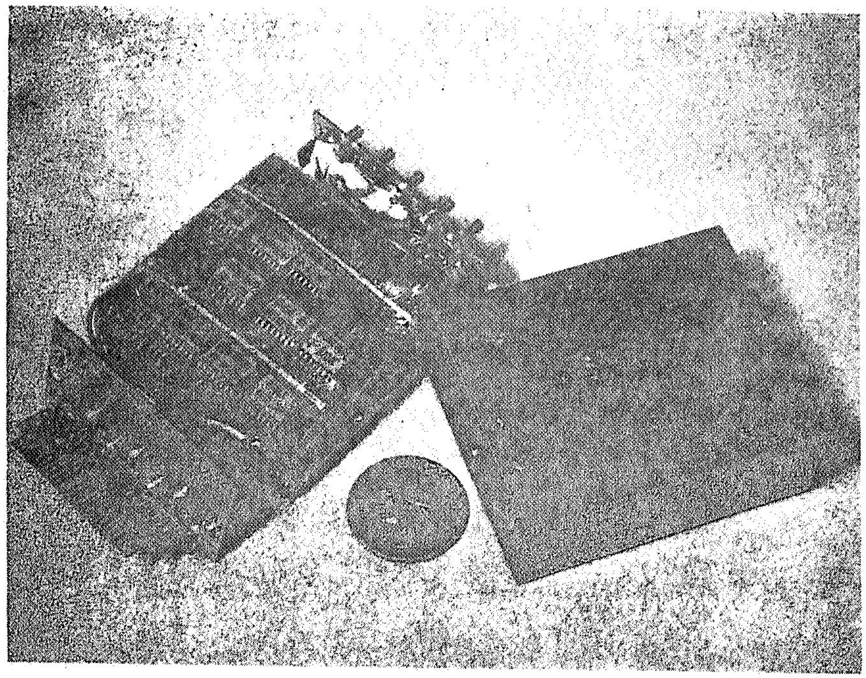


FIGURE A-7: PATIENT LOGIC AND DATA PROCESSING UNIT

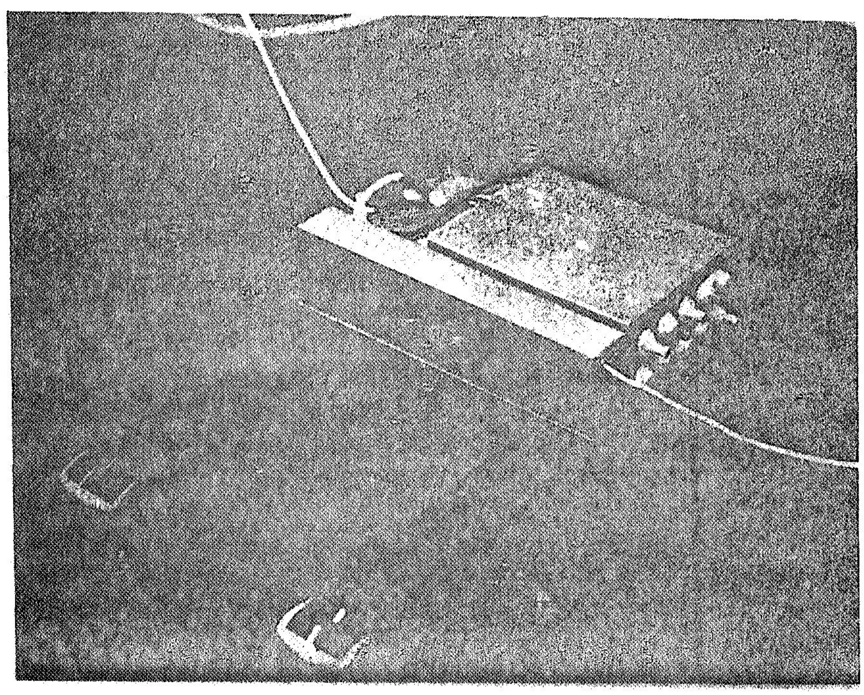


FIGURE A-8: PATIENT STRAP-ON UNIT

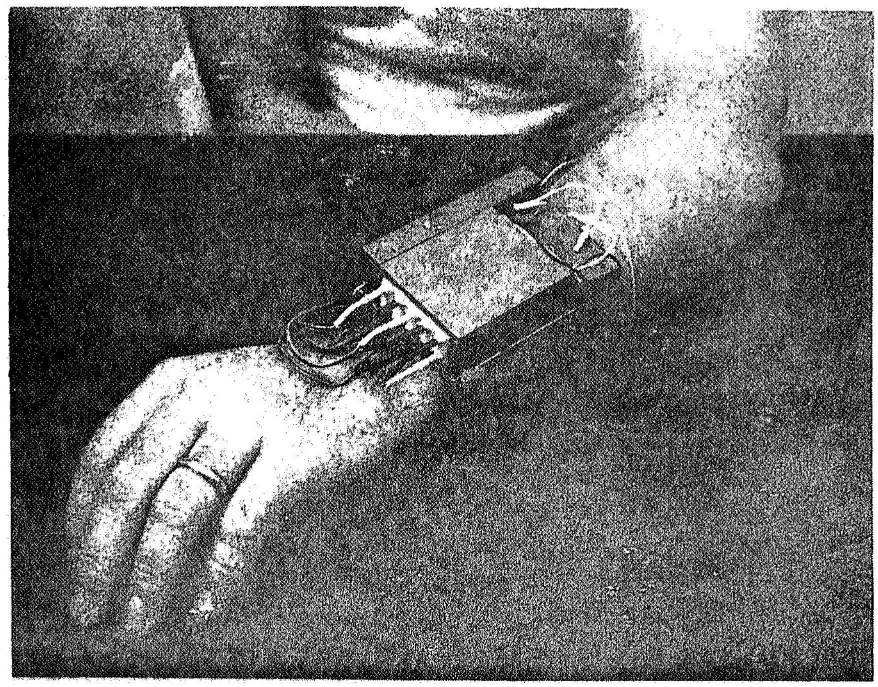


FIGURE A-9: PATIENT UNIT SHOWN ON "PATIENT"

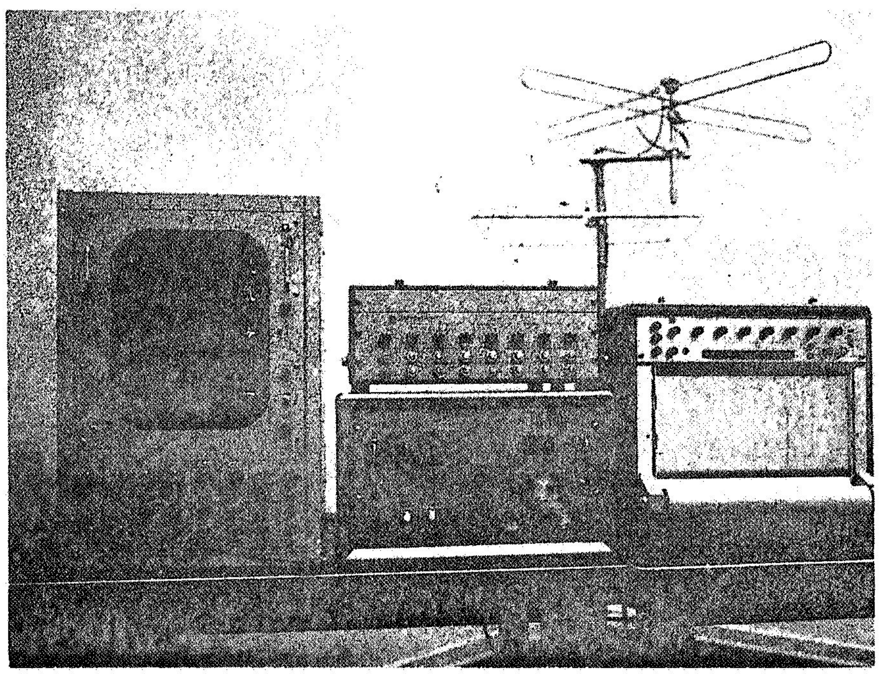


FIGURE A-10: CENTRAL STATION

APPENDIX B

This section contains Central Station and Patient Unit block diagrams similar to those of Figure 5-1 and 5-2 but with additional explanation and detail.

Also included are representative circuit diagrams showing the specific utilization of integrated circuit devices in the design of analog and digital networks.

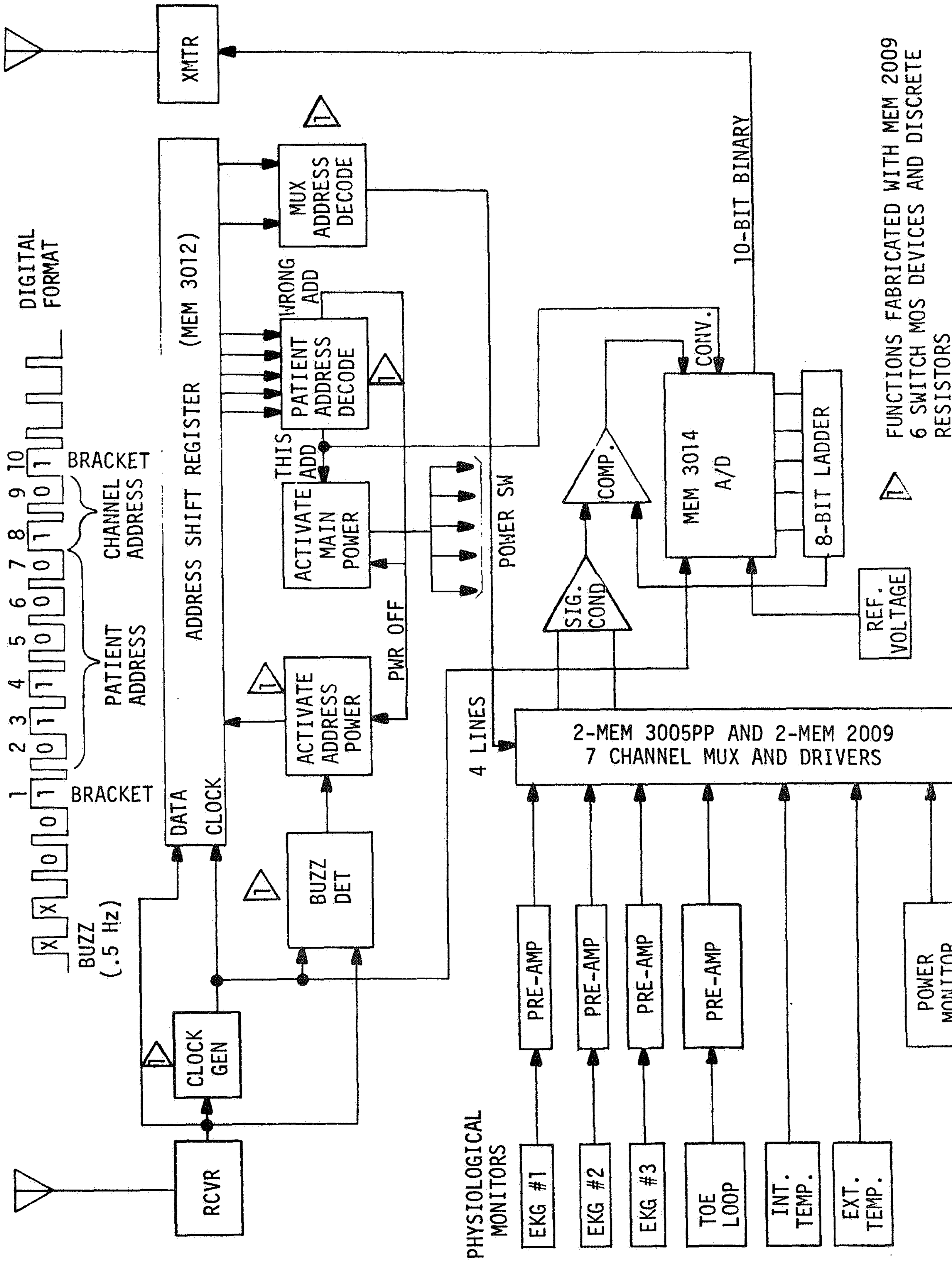


FIGURE B-1 AUTOMATED PATIENT CARE BLOCK DIAGRAM, PATIENT UNIT

APPENDIX B

TYPICAL PATIENT UNIT CIRCUITRY

SHIFT REGISTER FUNCTIONS - MSI MOS Devices (MEM 3012 SP and MEM 3005PP)

LOGIC FUNCTIONS - MEM 2009, 6-Switch MOS Flat Packs and Discrete Resistors

A/D CONVERTER - MEM 3014
μA710 Comparator
R/2R, 8 Bit Ladder Network

ANALOG FUNCTIONS - μA709 Operational Amplifiers

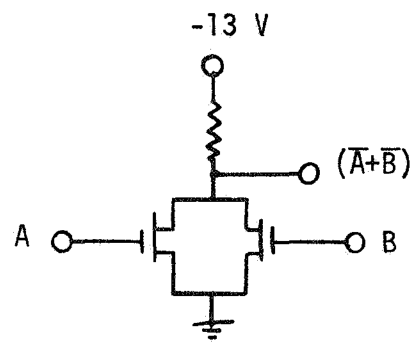


FIGURE B-2 MOS NOR GATES

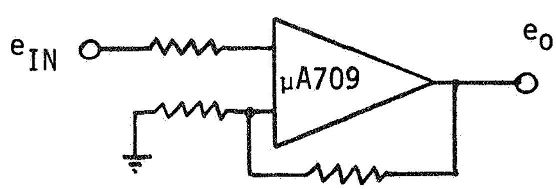


FIGURE B-3 HIGH INPUT IMPEDANCE PREAMPLIFIERS

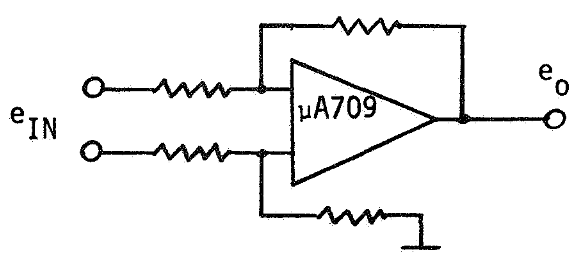


FIGURE B-4 BRIDGE (TOE LOOP) PREAMPLIFIER

APPENDIX B

TYPICAL PATIENT UNIT CIRCUITRY (CONTINUED)

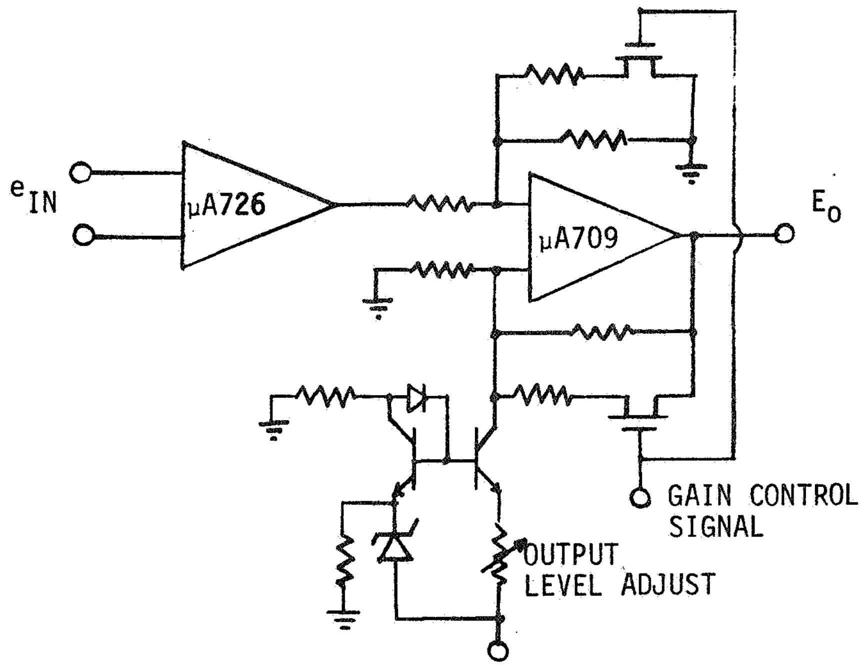


FIGURE B-5 PROGRAMMABLE SIGNAL CONDITIONER

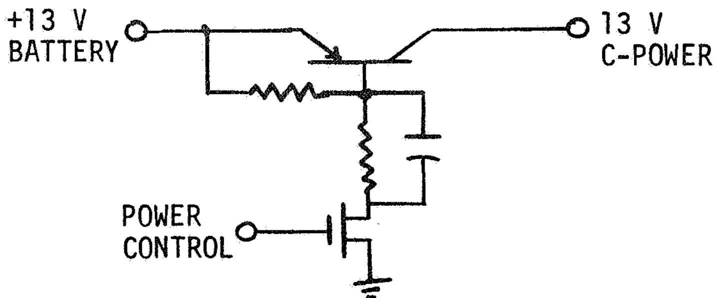
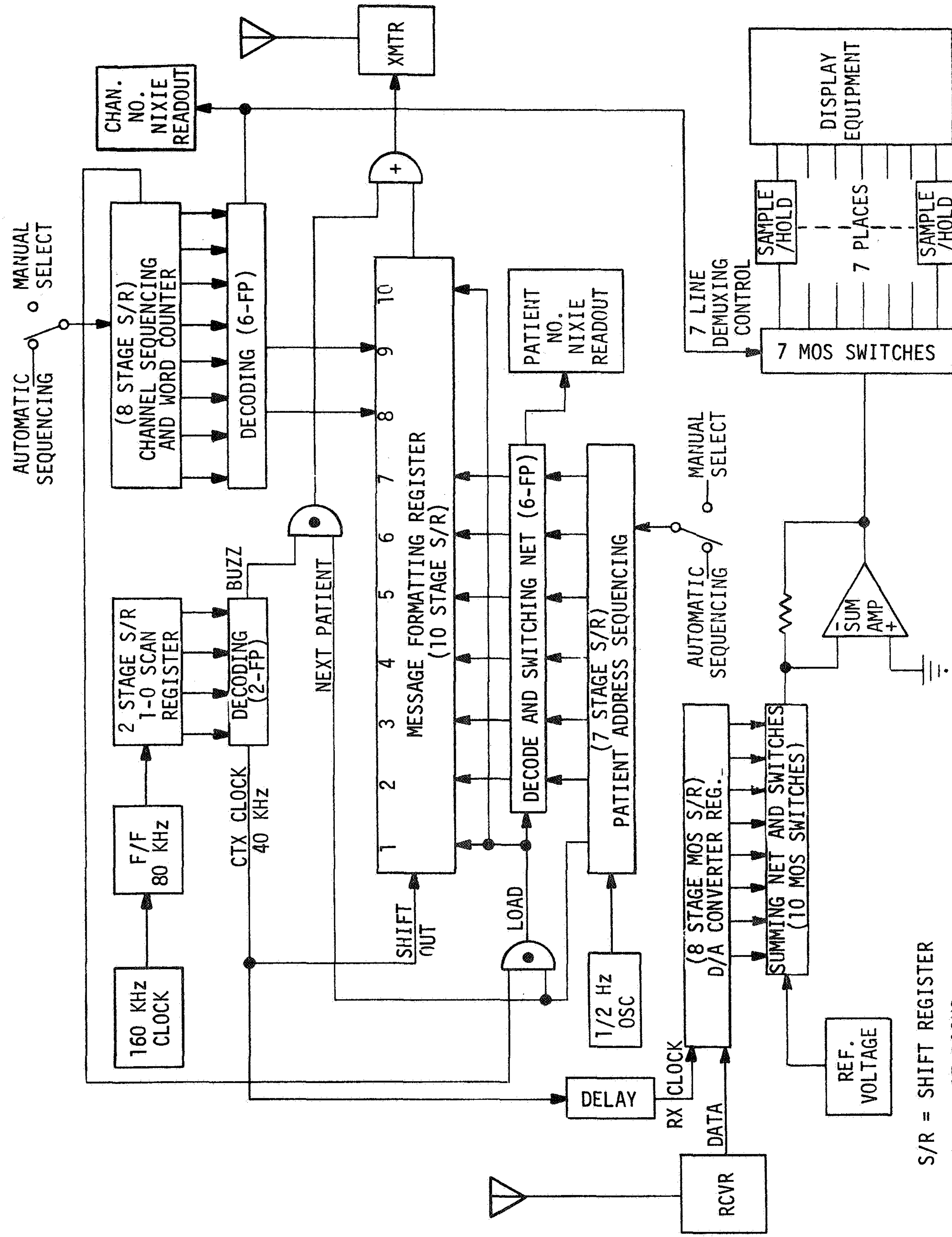


FIGURE B-6 POWER SWITCHING CIRCUITRY



S/R = SHIFT REGISTER

FP = FLAT PACKS

FIGURE B-7 AUTOMATED PATIENT CARE BLOCK DIAGRAM, CENTRAL STATION

APPENDIX B

TYPICAL CENTRAL STATION CIRCUITRY

JK FLIP FLOPS - N/C 826F
SHIFT REGISTERS - 1 JK Flip Flop/Shift Register Stage
DECODING - DTL 930 & 946 Nand Gates
CLOCKS, 160 Hz & .5 Hz - Unijunction Transistor Oscillators
ANALOG SWITCHING FUNCTIONS - 6 Gate MOS Flat Pack MEM 2009

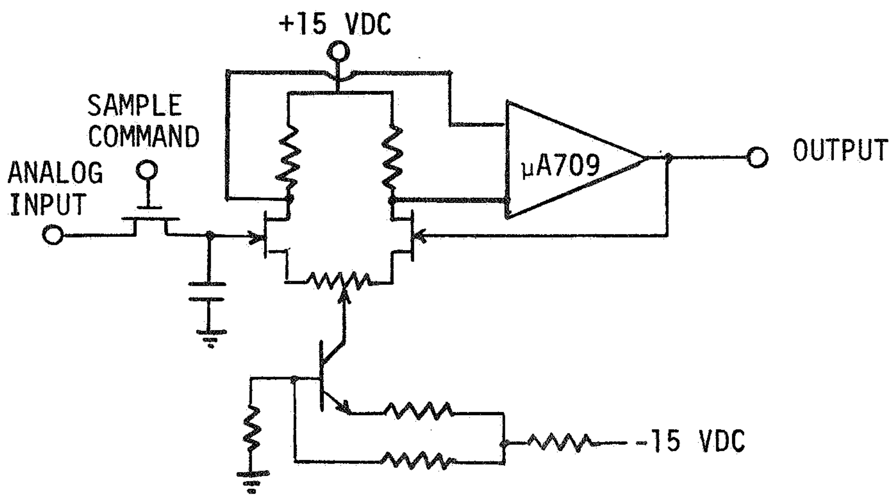


FIGURE B-8 SAMPLE AND HOLD CIRCUITRY

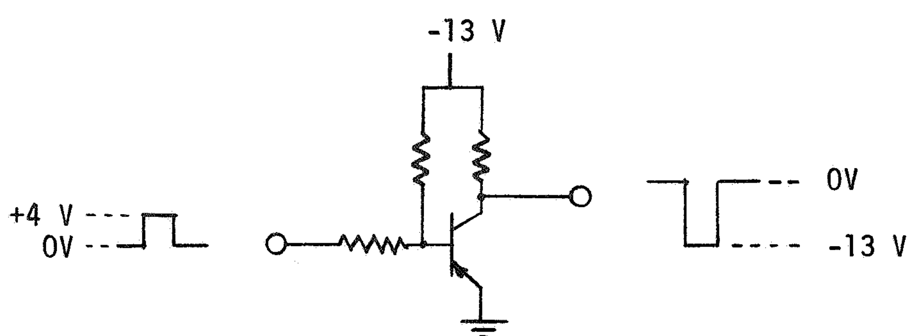


FIGURE B-9 DTL (SCIC) TO MOS INTERFACE CIRCUITRY

APPENDIX B

TYPICAL CENTRAL STATION CIRCUITRY (CONTINUED)

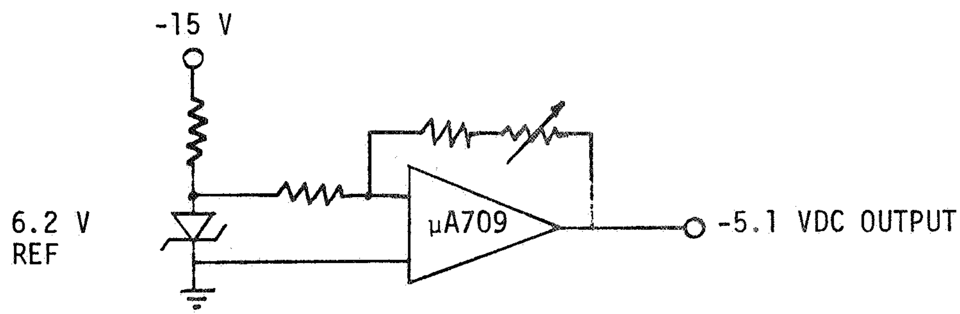


FIGURE B-10 REFERENCE VOLTAGE CIRCUITRY FOR D/A CONVERTER

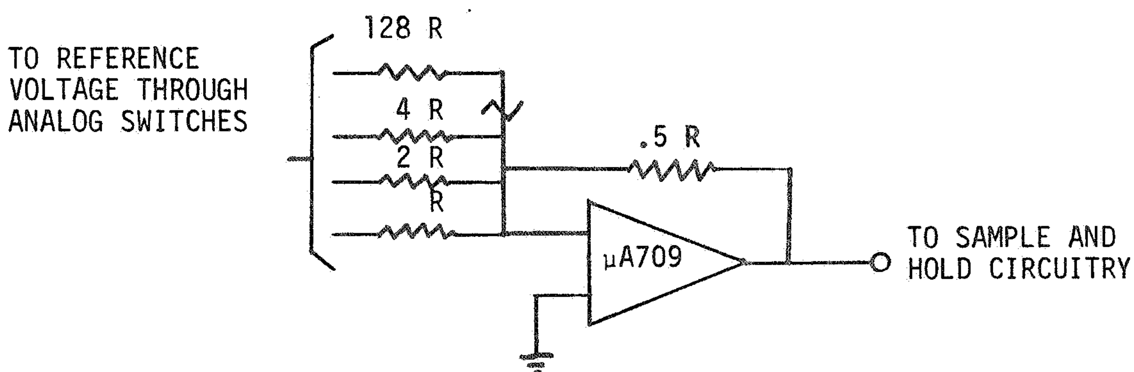
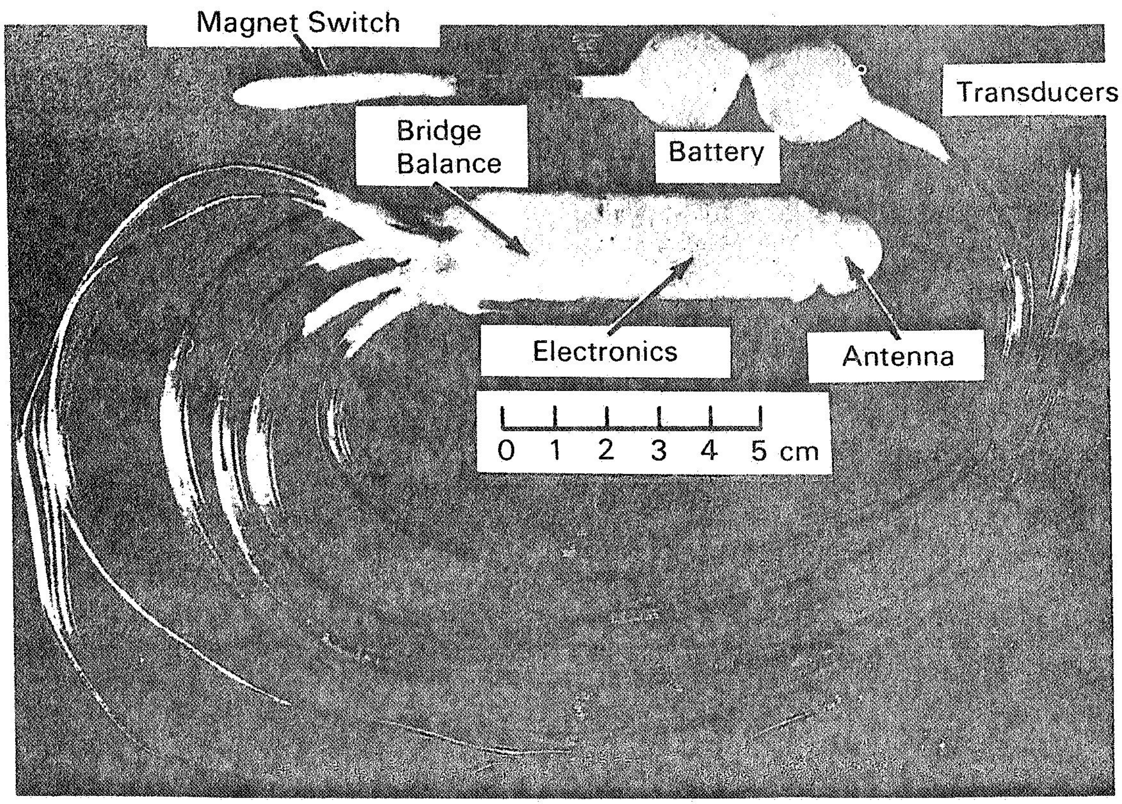


FIGURE B-11 SUMMING AMPLIFIER FOR D/A CONVERTER

NASA TECH BRIEF

NASA Tech Briefs are issued to summarize specific innovations derived from the U.S. space program, to encourage their commercial application. Copies are available to the public at 15 cents each from the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151.

Multichannel Implantable Telemetry System



The problem:

To develop a multichannel telemetry system suitable for chronic implantation in animals to monitor a variety of physiological parameters. It is desirable to design the system such that the number of channels can easily be increased or decreased depending upon the requirements of the experimenter.

The solution:

A hermetically sealed unit using a time-sharing multiplex scheme to commutate between various sensor inputs. To date experiments requiring multiple pressure sensors, EKG, and temperature have been accommodated. Units having 5 and 8 channels have been built and tested. The essential features of small size and low power required for implantable physiological telemetry have been achieved without sacrificing accuracy and reliability.

How it's done:

The telemetry system is shown as a block diagram. The upper section of the figure shows the implanted

(continued overleaf)

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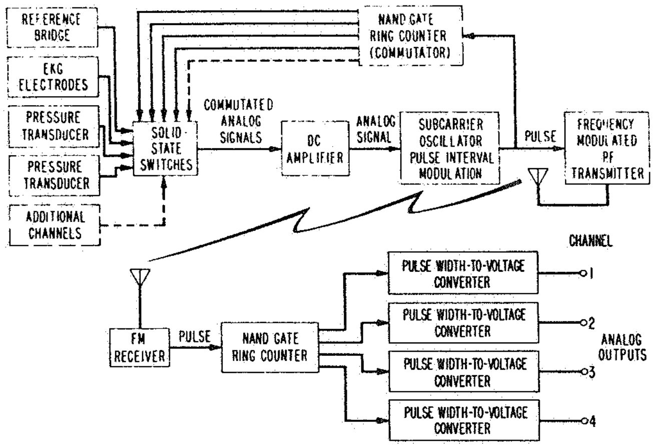


transmitter part of the system. The lower part of the figure is the receiving and demodulating equipment that provides an analog signal suitable as an input to a pen recorder.

The ring counter is the key element in the operation of this multichannel transmitter. A *nand* gate ring counter is used as a commutator to operate a series of solid-state switches. There is one switch for each input channel and these are operated in a sequential manner by the commutator. The commutated signal is amplified slightly and then applied to a subcarrier oscillator. The subcarrier oscillator is used in the system to allow accurate coding of the signal for RF transmission. The subcarrier oscillator generates a series of pulses with a period between pulses of approximately 0.7 msec. Each pulse generated by the oscillator is used to advance the ring counter and the solid-state switch one position to sample the next analog input. The oscillator pulses are also used to frequency modulate an RF oscillator. The RF signal is then radiated by means of an antenna to the receiving system.

Each sensor is connected to the transmitter by lead wires contained in medical grade tygon tubing. Another tygon-covered lead connects to the battery and a magnetic latching switch, which are usually placed just under the skin of the animal, to facilitate operation of the switch and renewal of battery. With this arrangement, long-term (1-2 year) telemetry experiments are possible.

Notes:

1. One of the multiple channels is used for reference and calibration purposes to obtain long-term system accuracy and stability.
2. The basic operation, except for the addition of a multichannel capability by means of a commutating switch, is similar to that of single-channel circuits that have been described in NASA Tech Briefs 64-10171, 66-10057, and 66-10624. These Tech Briefs are available from the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151; price $0.15 each.
3. The following is a summary of the major system performance characteristics:
   Number of channels—Systems with five and eight channels have been tested, but the system can easily be adapted to more or less channels.
   Sample rate—Approximately 0.7 msec per channel.
   Frequency response—DC to 50 Hz.
   Transient response—5 to 7 msec for five-channel system.
   Input impedance—Suitable for 5K strain-gage bridges, or approximately 150K when used with biopotentials such as EKG.
   Noise level—Less than 20μV peak to peak, including cross-modulation
   Radio frequency—88-108 MHz.
   Power supply—2.7 V(2 mercury cells).
   Battery drain—Approximately 2.5 ma for the transmitter system. (The total current required by the three pressure cells and reference bridge used in this instance is 1 ma.)
   Operating life—200 hours continuous operation using a 500 ma-hr battery.
   Size—Transmitter (independent of battery and transducers) approximately 1 cm by 2 cm by 8 cm.
   Weight—Transmitter, 70 gm. (Two 500-ma-hr mercury cells (pacemaker type); 16gm.)
4. The size and weight could be reduced further by using integrated circuitry.
5. An encapsulated transmitter has been implanted in a dog and heart measurements have been successfully telemetered to a distance of 200 feet.
6. Additional details are contained in a paper, *A Multichannel Implantable Telemetry System*, by Thomas B. Fryer, Harold Sandler, and Boris Datnow, which was presented at the 7th International Conference on Medical and Biological Engineering, August 15-19, 1967, Stockholm, Sweden. Copies of this paper are available from:
   Technology Utilization Officer
   Ames Research Center
   Moffett Field, California 94035
   Reference: B68-10065

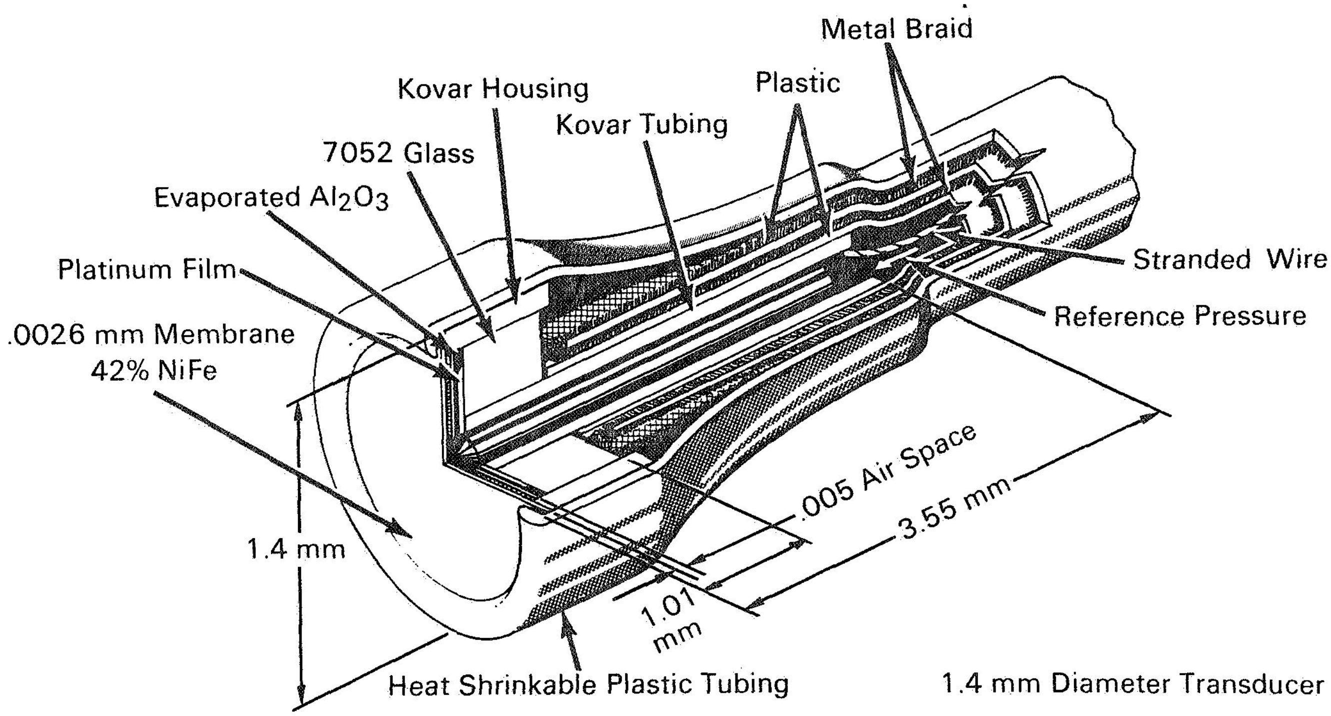
Patent status:

This invention is owned by NASA, and a patent application has been filed. Royalty-free, nonexclusive licenses for its commercial use will be granted by NASA. Inquiries concerning license rights should be made to NASA, Code GP, Washington, D.C. 20546.

Source: T. B. Fryer
(ARC-10083)

NASA TECH BRIEF

Ultraminiature Manometer-Tipped Cardiac Catheter



1.4 mm Diameter Transducer

A miniature diaphragm-type capacitance transducer capable of being mounted on the end of a cardiac catheter has been developed for measurement of intravascular pressures. Cells have been developed having diameters of 2.25 mm, 1.4 mm, 1.2 mm and most recently 1.0 mm. These latter cells have been mounted on catheters 100 cm long in order to allow for insertion of the pressure transducer and catheter by percutaneous techniques using standard 17 gage thin wall needles (ID = 1.1 mm) which are routinely used for venous or arterial punctures in humans.

A diagram of the 1.4 mm pressure cell is illustrated. The two plates for the capacitor used for sensing pressure consist of a cell diaphragm (1.4 mm in diameter and 0.0026 mm thick) and a film of platinum fired onto a glass core separated by an air gap of 0.005 mm. The central metal tube in the cell provides an electrical connection to the platinum film and for passage of reference pressure to the capacitor air space. Air passage through the cable is provided by the central plastic tube which may be left open to atmosphere or used for pressure calibrations.

The electronic system connected to the catheter for sensing pressure consists of a capacitance bridge network excited by a 100 KHz crystal oscillator, a low noise transistor amplifier and an appropriate demodulator to produce an analog signal (dc to 10 kc) for a recorder or display on an oscilloscope. The natural frequency of the 1.4 mm cell in air is 82 KHz. The cell is linear within 1% from 0 to 200 mm Hg with

(continued overleaf)

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a resolution of 1 mm Hg. Its temperature effect is slight with a zero shift of 0.15% FS/°C (25.5° to 44°C) and negligible sensitivity shift.

Units have been used to catheterize the left ventricle via the femoral and carotid arteries in dogs. A typical arterial tracing from the arch of the aorta is shown using the 1.2 mm catheter device compared to a simultaneously obtained tracing from the same site using a commercially available manometer-tipped catheter. The tracing from the capacitance cell has been purposely displaced downward to illustrate the similarity of wave forms.

These transducers are presently being evaluated in man. These manometer-tipped catheters, which can be inserted percutaneously through a needle, will replace techniques for measuring left heart pressures that use fluid filled catheters or procedures which require cut-downs on arteries for insertion of 7F to 9F catheters.

Notes:

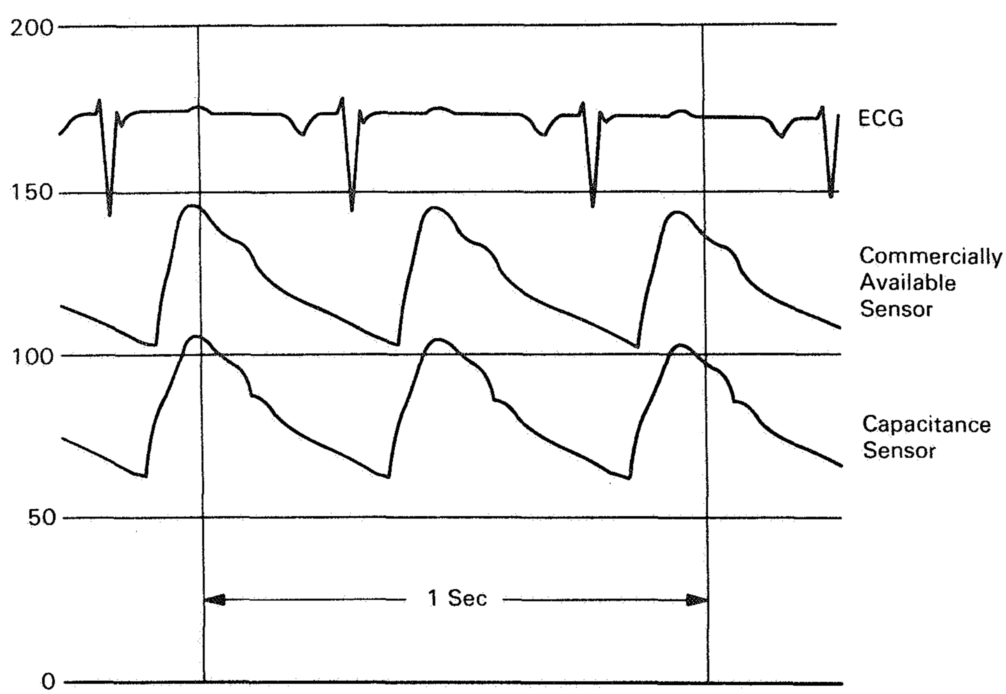
1. Although the principle of operation of this transducer is exactly the same as that described in the references, novel features of this invention are extreme miniaturization and the successful addition of miniature leads protected by heat-shrinkable plastic tubing which is compatible with fluids in the circulatory system.
2. By virtue of these improvements, the transducer can be inserted in smaller ducts (arteries and veins) without disturbing the flow characteristics. It would be very useful for making measurements in babies, for example.
3. These transducers were originally designed for use in wind tunnels for pressure survey probes and for the telemetry of pressure data from small free-flight models. Additional details are contained in:
   a. NASA Tech Brief: *Welded Pressure Transducer Made as Small as 1/8-inch in Diameter.* Brief 63-10429, March 1964.
   b. NASA Tech Note TN D-3319, *FM Telemetry and Free-Flight Techniques for Aerodynamic Measurements in Conventional Wind Tunnels,* by Ronald J. Hruby, John B. McDevitt, Grant W. Coon, Dean R. Harrison, and Joseph H. Kemp, Jr., March 1966.
4. Copies of these publications are for sale by the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151; Tech Brief $0.15; Tech Note $3.00.
5. Inquiries concerning this invention may be directed to:

   Technology Utilization Officer
   Ames Research Center
   Moffett Field, California 94035
   Reference: B67-10669

Patent status:

This is the invention of a NASA employee, and U.S. Patent No. 3027769 has been issued to him. Inquiries about obtaining license rights for its commercial development should be addressed to the inventor, Mr. Grant W. Coon, at Ames Research Center.

Source: Grant W. Coon
(ARC-10054)



Comparison of Typical Wave Forms

103-99
5-68

CARBON/GRAPHITE MATERIALS

NAR54404 IMPLANTABLE PROSTHETICS

NAR54888 MYOELECTRIC PROBES

NAR54889 EPITHECIAL BONE EXTENSION

NAR54890 IMPLANTABLE SPLINTS

NAR54891 COSMETIC BONE REPLACEMENTS

NAR54892 CIRCULATORY BYPASS IMPLANTS

NAR54893 REPLACEMENT HEART VALVES

CONTRACT NAS8-5604
NASA COGNIZANCE MSFC

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PARAMETRIC COMPARISON

The stringent requirements for high integrity of materials exposed to severe environmental conditions in many aerospace applications have resulted in the development of a variety of high-purity, high-strength forms of carbon, graphite, and composite materials with unusual combinations of properties. The upper portion of the chart compares metals, ceramics, and carbons in the light of both aerospace and biomedical needs. The balance of the chart lists additional characteristics currently believed to be particularly critical in materials for biomedical application.

103 100
5 68

PARAMETRIC COMPARISON

AEROSPACE & BIOMEDICAL

PARAMETER	METALS	CERAMICS	CARBONS
STRENGTH	HIGH	HIGH	FAIR TO HIGH
TEMPERATURE TOLERANCE	FAIR	HIGH	HIGH
CHEMICAL COMPATIBILITY	LOW	FAIR	HIGH
GALVANIC COMPATIBILITY	LOW	FAIR TO HIGH	HIGH
BIOMEDICAL ONLY			
TISSUE ACCEPTANCE	LOW	LOW TO FAIR	HIGH
NON-TOXIC	LOW	FAIR	HIGH
BODY FLUID RESISTANCE	FAIR	HIGH	HIGH
DENSITY MATCHING	LOW	HIGH	HIGH

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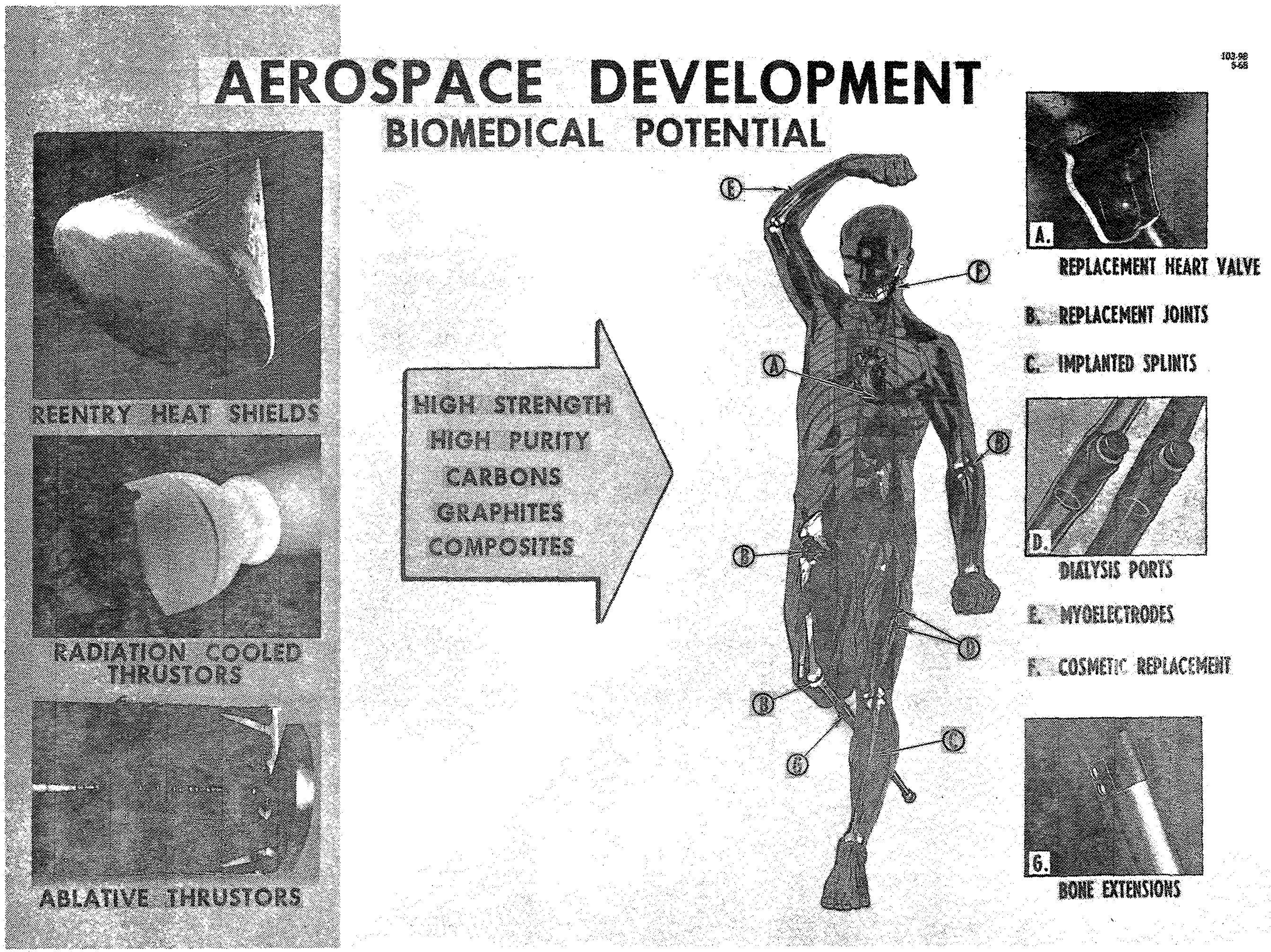
AEROSPACE DEVELOPMENT

Space re-entry devices and vehicles, rocket combustion chambers, and other aerospace-associated equipment frequently encounter environmental conditions considerably beyond the capability of conventional materials. The development of new forms of carbon, graphite, and composite materials capable of high integrity under these severe conditions has produced combinations of material properties not previously available that give promise of being directly applicable to biomedical requirements. As indicated on the previous chart, pure carbon, in any of its various physical forms, indicates substantially higher biocompatibility than other structurally satisfactory materials. This is generating some interest in those segments of the medical profession involved with "replacement parts" for the human body. The chart indicates seven possible applications that have been identified to date. Preliminary laboratory investigations directed toward five of these applications have been undertaken by Rancho Los Amigos Hospital and UCLA Medical Center doctors.



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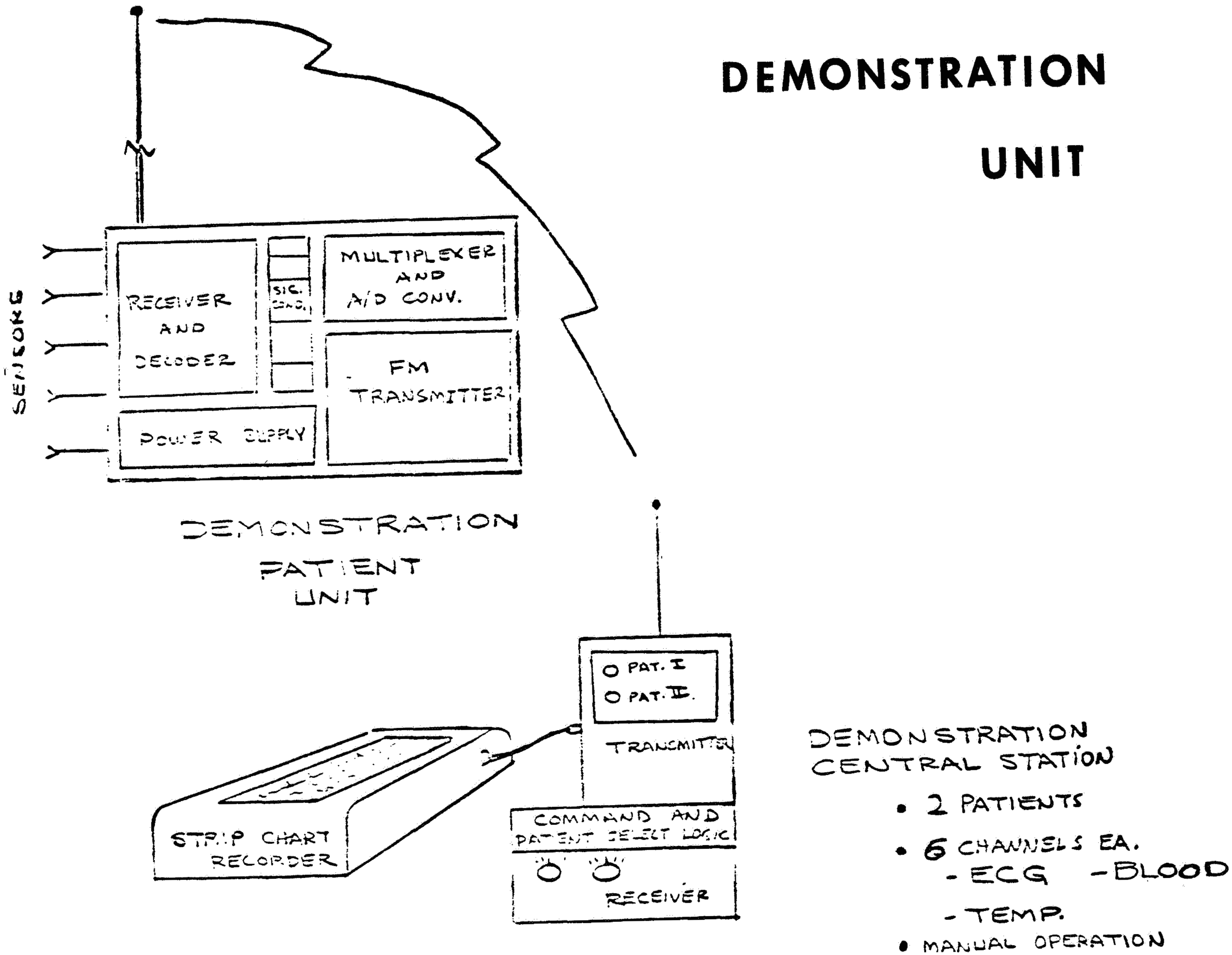
DEMONSTRATION UNIT



For additional information on this system or other NASA developments which might be of interest, you are invited to contact the Technology Utilization Office of the nearest NASA Center.

The Automated Patient Monitor System is coded as MFS-14552, and inquires concerning this particular concept should be directed to:

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Attn: Technology Utilization Office, MS-T
MFS-14552